ENGLAND'S NEGLECT OF SCIENCE

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BY

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PREFACE

AS from the leading article in *The Times* of November 9th, and from the articles and letters now appearing in the daily and weekly papers in which my address as President of the Institution of Electrical Engineers is being criticised, it appears that I am regarded as now putting forward views that are quite new, I think it well to publish some statements which I have made in the past. It will be seen that these amplify certain parts of the address which have not been perfectly well understood. It will be seen that there has been no essential change in my notions as to what kind of reform is needed in what is called our System of Education. I have recently come to know that these notions are in perfect agreement with what Mr. Herbert Spencer and many other educationalists have published. They are certainly the notions of my old colleagues, Professors Ayrton and Armstrong. I cannot lay my hands on certain statements which I published in Japan between the years 1875 and 1879, but these as well as many other of my utterances since are in perfect agreement with my notions now. I claim that these notions are natural to any man of experience who can think for himself and who is not materially interested in the maintenance of existing methods of education.

JOHN PERRY.

ROYAL COLLEGE OF SCIENCE, LONDON, S.W.
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PRESIDENTIAL ADDRESS TO THE INSTITUTION OF ELECTRICAL ENGINEERS, NOVEMBER 8, 1900

I DO not intend to make this in any sense a report of the progress of our Institution during the last or any number of years. I shall not, therefore, give any account of the exceedingly good work done by Colonel Crompton and the active service corps of our Electrical Engineer Volunteers in South Africa. I shall not describe how we *fêted* our American cousins in England and France, nor how they *fêted* us; nor what a wonderful success accompanied all that was attempted by us or by them or by M. Mascart and our French colleagues, although I cannot refrain from bearing my testimony to the great kindness of the Prince of Wales and the British Commission in so generously lending us the British Pavilion for our great reception and giving us the use of one of its rooms for our office all the time of our visit to Paris.

My brother has tried to get me to introduce to your notice some novel ideas which have come to us during the last ten years in our business of lighting the City of Galway from a fairly constant water-power using accumulators with a Dowson gas plant stand-by. It has almost come to be a practical idea to produce Carbide of Calcium in wet seasons and utilise it through the gas engine in dry seasons. I was also tempted to discuss the use of large gas engine plant at central stations; and another of several subjects in which I have been recently engaged has been the magnetic effect produced by systems of electric traction. But I have resisted temptation and have chosen a subject which seems to me much more important.

Your president's address is followed by no discussion. He is, therefore, privileged, but his very privileges cause him to address you with a greater sense of responsibility; he may say what he pleases, but he must be very sure that he has the best interests of the Institution at heart; the interests of the Institution as a whole, not the interests merely of a few members, and least of all ought he to think of his own interests. Nevertheless, your president speaks not as an omniscient judge, but rather as a very fallible, very prejudiced one-sided man who, because he has devoted himself to one part of the work of this Institution, is certain to be unfair in his comments upon other parts of the work.

Your past presidents represent in this way all classes of members of this Institution. You have had scientific men, given, some of them to calculation and some to experiment and some to both; men who have advanced the study of pure science. You have had practical telegraph men, civil and military, men cunning in land and deep-sea telegraphy and telephony; men cunning in railway signalling. You have had electrical chemists. You have had manufacturers and users of all kinds of electrical appliances. You have had men who devote themselves to the teaching of electrical engineers, and who fully appreciate the fact that no good teacher ought to be out of practical touch with the profession. And nearly all your past presidents have invented things which are now in practical use.

As each of these men has given you at least one address written from his own peculiar point of view, his prejudices are not likely to have done any harm to members who read the other addresses. I know, therefore, that you are good-naturedly prepared to give me plenty of rope. I can predict the twinkle of amusement in the faces of some of my friends when they learn that I am about to take up a subject on which we have had many debates. Your attention has just been attracted to the curves showing the numerical growth of our Institution in membership, and this has been marvellous, but I would speak of something more than mere numbers, namely, the *quality* of our membership. In fact, I mean to put before you this simple question: Is electrical engineering to remain a profession or is it to become a trade? Is this Institution to continue to

be a society for the advancement of knowledge in the applications of scientific principles to electrical industries, or is it to become a mere trades union ?

Of course, at the present time the outside public are willing to regard membership of this Institution as a Symbol of something more than the membership of a mere trades union. During the early growth of any trade, even such a trade as that of the plumber, it was really a profession. And a common trade may suddenly become a profession, if it suddenly begins to develop, as, for example, stone-masonry of a hundred years ago suddenly developed into civil engineering. Electrical engineering has been developed rapidly, so that in the past it has certainly been a profession and not a trade.

Again, we are an institution of engineers, and the general public are willing to class us with other engineering institutions—for example, the Institution of Civil Engineers. Now the title M.Inst.C.E. is a professional distinction which represents in civil engineering what F.R.C.S. does in surgery, or M.R.C.P. in medicine. We owe a great deal to our association with, and recognition by, the Institution of Civil Engineers ; our meetings are held in its rooms ; many of our members are also its members ; our proceedings are modelled on its proceedings.

Now this older Institution, governed by the best thoughts of the best British engineers, has laid it down that its associate members, that important class from which the higher class is mainly fed, shall have passed certain specified examinations in pure and applied science.

I am not now suggesting that we ought to adopt this science examination method of admitting any kind of members to our Institution. I do not believe in the wholesale adoption of methods of working from another society. I am asking you early in my address to remember that this greatest of all professional engineering institutions, governed by practical men full of common sense, knowing the wants of their profession well, insists upon a knowledge of science in its new members. If this recognition of science did not exist anywhere else in the whole world, I say that its recognition by such a thoroughly good professional society as that of the Civil Engineers ought to recommend it to all professional societies.

In Germany an enormous stride has recently been made in the raising of Engineering degrees to rank with the highest University honours. There is hardly one engineer of eminence in Switzerland, France, or Germany who has not passed with honour through the classes of one of their great science Universities.[1] In Great Britain within the last fifteen years not only have great engineering schools been established in all the manufacturing towns, but even in Cambridge University there is one of the best schools of civil, mechanical, and electrical engineering of which I know anything.

Before we think of imitating the Institution of Civil Engineers, we ought to reflect on certain fundamental distinctions between that Institution and our own which at first sight seem to make us less professional.

There is a well-known unwritten rule of the Civil Engineers to which there are only a few exceptions, that no contracting railway or harbour engineer can acquire the title of M.Inst.C.E. I think myself that it is a pity to draw a hard and fast line between consulting engineers and contractors. No doubt it simplifies the labour of the Council in its selection of candidates, but it gives rise to anomalies.

A man who was once a civil engineer because he served a pupilage under his clever father, and who now is nominally at the head of his father's large practice, the real engineering work being done by many clever employees, this man may be a member. A contracting engineer who shows marvellous ability not only in rectifying the mistakes of the designer of a large bridge or tunnel or reservoir embankment, but shows the power of Lord Kitchener in directing the work of thousands of men so that no man need be idle, and the whole contract goes on like clockwork, and is finished well in the minimum of time, this man is ineligible. Now in our Institution it has been recognised from the very first that manufacturers and contractors and their employees

[1] I understand also that the great unions of manufacturers in *Germany* are about to make facilities for giving a year of real factory work to the Polytechnic students, thus perfecting the German system. In Japan we found great success in requiring students to spend their summer in real shops, their winters at college. In England it may be that we shall prefer to let all apprentices have shorter factory hours than workmen, articled pupils much shorter hours, their masters being responsible for instruction being given in theory.

may belong to the very highest ranks of their profession. Of course, I do not mean men who simply receive the profits of businesses, or even men who merely work to obtain orders for themselves. I mean men who are not merely formally but in reality manufacturing or contracting engineers. I mean men who, in dealing with standardised things, design new methods for quick, good, cheap production of such things. I mean men who improve old forms of things, possibly through their paid subordinates. I mean by a manufacturer fit to be a M.I.E.E a man who might act as his own manager, and who, perhaps, has a wider outlook than on mere managerial duties. So long as a contractor or manufacturer is really an engineer, we know that we add to our strength with the addition of every such member.

But consider a contractor who only uses ordinary types of machines or electrical plant in well-known ways, surely he can hardly be said to be in the profession at all. Surely the one thing that differentiates us from mere tradesmen is that we do not follow mere rule of thumb methods ; we think for ourselves, we weigh advantages and disadvantages. If every new installation required the same treatment as existing ones, the engineer would degenerate into a tradesman, and it seems to me that the electrical engineer ought to have a special fear of such degeneration.

In railway and harbour and river and sanitary engineering, in every new job there are new difficulties to be dealt with. An engineer who designs many undertakings and sees them carried out must be a thoughtful man ; he cannot help keeping himself acquainted with engineering principles, and so he is a professional man. So an architect finds that each new job requires all his experience. Every case that comes before a real physician or surgeon requires a somewhat different treatment from any old case. Every case brought before a barrister requires the exercise of all his past experience. In every case a *profession* implies the necessity for the exercise of all the outcome of one's past experience ; because the work one has to do is never the same as any work one has ever done before. And when I say the outcome of past experience, I really mean certain general principles which one has always in one's

mind, principles derived from all that one has done or seen or read about.

Electrical engineering is in a curious position. It owes its being altogether to scientific men, to the laboratory and desk-work of a long line of experimenters and philosophers. Even now the work going on in a laboratory to-day becomes the much larger work of the engineer to-morrow. When at length the laboratory experiment is utilised in engineering, we see that there is no other kind of engineering which so lends itself to mathematical treatment and exact measurement. Most of the phenomena dealt with by the electrical engineer lend themselves to exact mathematical calculation, and after calculations are made exact measurements may be made to test the accuracy of our theory. For a completed machine or any of its parts can be submitted to the most searching electrical and magnetic tests, since these tests, unlike those applied by the mechanical engineer, do not destroy the body tested.

Contrast this with the calculations it is possible to make in other kinds of engineering. The pressure of earth against a revetement wall is possibly 200 or 300 per cent. greater, or 50 to 70 per cent. less than what we imagine it to be in what some limited men call theory. We use factors of safety 5 or 10 or more on all kinds of iron structure calculations, because we are aware of our ignorance of a correct method of dealing with the problems. The civil engineer never has exactly the same problem as has already been solved. In tunnelling, earthwork, building, &c., in making railways and canals, he is supremely dependent on the natural conditions provided for him: the configuration of the surface of the ground, the geological formation, the structural materials available in the neighbourhood. The story of how the engineer has to study the endlessly different ways of interaction of water and sand and gravel is told by the troublesome bars at the mouths of rivers all over the world, by the difficulties of coast and river-bank protection, by the failure of sea walls and piers. But why should I make a catalogue of the different kinds of work done by civil engineers? Every one of them needs the exercise of general scientific principles due to much experience.

Now of all such natural difficulties the consulting or

contracting electrical engineer is greatly independent. Give him a source of power and tell him what is to be done; whether he is to light a town or a building, whether with arc or incandescent lights; whether he drives a stamp mill near a mine or a pump, or a machine tool, or a spinning frame, the electrical part of the work is carried out in much the same way. Natural conditions affect him mainly in the cost of transport of his materials and the cost of labour. He can make in an easy way the most careful calculations as to the best arrangement of his conductors and machines to give maximum economy, and except for this easy calculation his work is that of a mere tradesman. He is practically independent even of the weather. There are, indeed, some of us who grumble that this easy calculation is not made easier still, who prefer to make arithmetical guesses rather than exact calculation, because perhaps we like to see a little uncertainty introduced into the problem to make it more like a problem in civil engineering. I want members to see clearly that as time goes on, as our electrical engineering work gets more and more cut and dried, the man who loses the power to calculate, who loses his grip of the simple theory underlying our work, must sink more and more into the position of a mere tradesman who has no longer the right to call himself an engineer.

An electrical engineer must have such a good mental grasp of the general scientific principles underlying his work that he is able to improve existing things and ways of using these things. It has become the custom to call this *theory*, and I suppose I must follow the custom. I should prefer to call it *Science* [1] or *knowledge*. Do you remember Huxley's definition of Science? "Science," he said, "is organised common sense"; and this is really what I mean. Well, calling it *theory*, the man who is permeated by theory, whose theory is so much a part of his mental machinery

[1] What Doll Tearsheet said of the word "occupy" we have to say of the word "Science." It is used by many people out of its proper meaning and then condemned, so that one is getting afraid to use it. In Prof. Fitzgerald's splendid inaugural address to the Dublin Section of this Institution he says: "As has recently been pointed out to me by Dr. Trouton, it would be impossible to say the same contemptuous things of *knowledge* as are said of *Science*. In Germany the word used, 'Wissenschaft,' is the one corresponding to our word 'knowledge,' and there nobody of any sense could say that 'knowledge is all humbug,' as is here often said, and still oftener thought, of 'Science.'"

that it is always ready for practical application to any problem, he is the real engineer. But you must not mistake me in this matter. Eighty per cent. of the men who pass examinations in mathematics, mechanics, and electricity have very little of this theory. Fifty per cent. of the writers of letters in the engineering journals in which mathematical expressions occur have almost nothing of this theory in their possession. It is unknown to foolish men. Books alone, lectures alone, experiments alone, workshop experience alone cannot teach this theory. The acumen of a Q.C. may actually prevent a man from acquiring it. A man may have much of this theory, although he may never have listened to lectures, although he may dislike the sight of a mathematical expression. I have known men who might be called illiterate to possess much theory. I have known many men who might be called good *electricians* who are almost wanting in the theory necessary for the electrical engineer.

I am speaking only of theory. Of the other qualifications for an engineer I need not here speak; they are present to the minds of all of us. A man may have any amount of knowledge; he may know how to apply his knowledge, and yet he may not be able to apply the knowledge from a want of engineering *character*.

The engineer must be a real man; he must possess individuality, the power to think for himself. He must not be like a sheep, knowing only enough to follow the bell-wether. Over and over again in the last thirty years have some of us given our students much the same sort of advice that Baden-Powell gives to scouts in that excellent little book of his. If any of you have not read that book you ought to buy it at once, and you will there find that if a man is to think for himself he must possess all kinds of knowledge, he must be constantly picking up new kinds of knowledge.

Nobody can limit the value of any kind of knowledge, but still one may say that certain things are probably more important than others. To gain what we call "theory" a good general education is most helpful — mathematical knowledge is very helpful; laboratory and workshop experience are extremely helpful. There is one qualification which the electrical engineer must have and without which all other qualifications are useless, and if a man has it no other

qualification is supremely important, and this absolutely indispensable qualification is that a man shall love to think about and work with electrical things. He must like these not because of the money he can make through electrical contrivances, nor even, I think, because of the name he may make before the world—this would be mere liking or cupboard love which has no lasting quality. So long as we have men in this country who have the true love for scientific work of which I speak, so long shall we have a real profession of electrical engineering, for such men are always scheming new contrivances and improving old ones and utilising the services of all helpful people, and especially of capitalists. When we have reached a state in which nobody schemes new things because the existing things are perfect there will no longer be a profession of electrical engineering. Of all ideas surely that of having reached *perfection* is most hateful: the idea of exact knowledge, that nothing is unknown, that there is no need for thought and therefore that to think for oneself is a sin.

And so, although we are all agreed that much standardisation in our contrivances and methods is absolutely necessary for our competition with other nations, we must follow the Americans in this matter and take care that it does not destroy invention. Of course when things are really standardised, when we have our perfect Mauser rifle or dynamo or locomotive or traction engine or electrically driven stamp mill, a Boer can buy or even manufacture them if he has money, and he can use them as well as, or possibly better than, we can. But he is not an engineer. He uses things after the engineer has done his work upon them. A stoker, a common engine-driver, the guard of a train, these are not engineers. You must have noticed that the American engineers, who surely deserve the character of being practical idealists above all other engineers, are the men who are most imbued with notions of standardisation which lead to cheapness of manufacture, and they are also the men most alive to the necessity for occasional extensive scrapping of types of machinery when they become even a little antiquated.

Our chiefs, the men who run us all, our real men at this Institution, may be called Practical Idealists. They have imagination and judgment and individuality. They have

the imagination and enthusiasm of inventors, and yet they are more than inventors, for they can estimate the worth of their own inventions and control their imaginations. They are ready to receive all new ideas, they welcome all new things, and yet they are not carried away. They are radicals and yet they are conservatives. They have what Mrs. Beecher Stowe called *Faculty*.

A strong imagination well under control, surely it is the greatest of mental gifts. I look round me and wonder how many of us really have it; and how many of us are only dull men, who scorn novels and poetry, who live utilitarian, material lives, whose aim is merely to make money through electricity, who love it not for its own self, who cherish their "tuppeny-ha'penny-worth" of theory because it is sufficient for their immediate wants. Why, even the writers of leading articles in the daily papers can talk of the wonders of electricity and what may yet come to pass; and yet we who make machines and use them and switch the marvellous thing on and off and take all sorts of liberties with it—we are like Calibans oblivious of the wonders of the fairy isle—like soulless priests making a living in the temple of Isis—like Aladdins who rub our lamp only to get the necessaries of life.

Twenty years ago some of us were laughed at for our optimism, and yet everything that we declared then to be doable has now actually been done by engineers, except the thing which was then and is now declared to be the supremely important thing, namely, the electric consumption of coal. We say now, as we said then, "The applied science of the future lies invisible and small in the operations of the men who work at pure chemistry and physics." And think of the wonderfully rapid rate at which laboratory discoveries have been made in the last eleven years, and how as the years go on they become more and more numerous; and yet many of us plod along with our work seeing no farther than our noses. A year is now more pregnant with discovery than a hundred years used to be, and yet the protective stolidity of our ancestors is upon us and we think of the latest discovery as if it were really the very last that can be made. A thousand men are measuring and trying new things in laboratories all over the world. Some of them plodding and soulless; others of them with imagination

and clearness of vision. Do you think that nothing is to come from all that work?

And is it not one of the most important functions of the engineer to do as Mr. Marconi has done, to convince capitalists ignorant of science that if the successful laboratory experiment is tried on the large scale it must also be successful? And are we going to leave all this pioneering work, with all its possibilities of great gain, albeit with possible loss, to foreign engineers, when in most cases the scientific discovery has been made in England? Are we so lacking in the hope and faith which are born of imagination and science? And must we in the future as in the past have to rely upon the influx of the clever foreigner like Sir William Siemens? Must we, Boer like, always depend upon our Uitlander population, Fleming and German, Hollander, Huguenot and Hebrew, for the development of our natural resources?

Some of the best engineers I know are so exceptional that one must class them with geniuses; they have faculty and character, and so they have become engineers even under the most unfavourable circumstances. They have passed through ordinary schools and yet developed common sense. They were pitchforked into practical work, and their liking for the work as well as some curious kind of instinct led them to pick up all sorts of knowledge which have become part of their mental machinery. They continue to pick up new kinds of knowledge when these become necessary for their professional work. Unfortunately these men do not realise how exceptional they are, and they advise boys to go direct from school into works. They forget that the other 99 per cent. of men treated in the same way as themselves can only become the hewers of wood and drawers of water to real engineers. Treated in this way average boys are just like so many sheep: they learn just what seems absolutely necessary and no more; their acquaintance with the scientific principles underlying their trade is a hand-to-mouth knowledge which becomes useless when their trade undergoes development.

In 1867 I was an apprentice, and when in the drawing office and pattern shop I remember well how I was chaffed for studying such a non-paying, non-practical subject as elec-

tricity. When I published my first electrical paper in 1874 before the Royal Society, and even for some years afterwards, the real students of electricity in England could be counted on the fingers of one's hands. Many of us remember the first Gramme magneto machine that came to this country, a scientific toy, in 1874. How many engineers dreamt that a great new branch of engineering had been started? Even in 1878 engineers were as a rule quite ignorant of electricity, and since then every year, although newspaper writers have talked largely of the age of electricity, the men actually engaged in electrical industries have acted as if the greatest of changes were not perpetually going on in it. To be left behind, or to become camp followers, children of Gibeon, this is the usual fate of the men who scorn theory. In 1882–4 we used to have to pay men £200 and £300 a year because they had a slight knowledge of electrical matters. In 1884–6 these very men were not worth twenty shillings a week, they were weeded out of the profession and their places were taken by men of better knowledge. Two or three years after, these better men were again found to have been weeded out, because men of still better knowledge were available. And so it has gone on ever since. Men learn just enough to get posts; they settle down in these posts and scorn theory. They actually forget what little theory they once did possess. They know a great deal about existing machines, but presently they discover that improvements have been going on, and that they no longer have a right to say that they belong to the engineering profession. In every year one has told men, "You will be left behind. See A and B and C. I told them three years ago, when their names were in everybody's mouths, that they would be left behind like their predecessors, and they laughed. Now I tell you and you laugh, and you also will be left behind. Yes, I know that you get a good salary or large fees, and your head touches the sky. Nevertheless, because you neglect theory and the simple mathematics by means of which theory is made available in practical problems, you will have to take a back seat presently, for our profession is in its early youth and is growing rapidly."

Remember that I do not now refer to the few exceptional heaven-born engineers who, in spite of bad training,

do manage somehow to pick up the necessary knowledge. I speak of the average men, many of whom are now living in the same old fool's paradise. They know enough for present needs ; they scorn the simple principles which underlie all our work ; they scorn the easy mathematics by which these principles are most readily employed in practical problems ; they will have their reward.

Just think of what is occurring at the present time. In England we have cheap coal, and it can be carried easily. In Switzerland and other countries where there is no cheap coal the water-power had to be utilised and power had to be transmitted great distances electrically. This needed high voltage, and as it is difficult to get high voltage with direct current machines, alternating currents were used, and on account of motor troubles multiphase working has been introduced. What a revelation it was to almost all of us, that visit of a year ago to Switzerland! We saw enormous schemes of lighting and traction and power. We saw electric trains driven by distant waterfalls sandwiched in among ordinary trains keeping proper time on working railways. We had known that there were great schemes carried out in Germany and America and other countries, and yet all the machines were quite unfamiliar to us. We were very much like what engineers of 1870 would have been if suddenly brought into a generating station. Is it not a fact that some of us, said to be eminent and thought to be practical, asked questions and made remarks which showed that we did not know the most elementary principles of three-phase working. Is it then any wonder that the traction schemes now being developed in England, on lines that are certainly not the best for this country of their adoption, are altogether dependent on the use of foreign electrical machinery and employ foreign electrical engineers? I am not putting this altogether fairly, for municipal procrastination has prevented our development, and yet I am not putting it altogether unfairly. We know too little theory.

I am afraid that just now we are in a rather tight place. I would give something to know how we in this room are going to get acquainted with what some people rightly or wrongly consider the most important kind of modern electrical engineering. Our usual way of learning is by

actual handling of things. But if the millions of pounds' worth of machinery coming to England every year is all foreign and is used mainly under foreign superintendence, our usual method of study is made very difficult. True there are American and German, and indeed a very good English publication which would give a knowledge of the theory, but not, I think, to the average English electrical engineer. I know of many men 25 to 40 years of age who seldom come to our meetings, and who say they are silent in discussions because they cannot be understood; perhaps these men will find a way to save us all from being left behind. There is much more that I might say in this connection. An individual Englishman may be left behind other Englishmen, and all English electrical engineers may be left behind the rest of the world, but all electrical engineers of the world may even be left behind other appliers of science. It is not merely that the incandescent mantle of the gas engineer is improving and necessitates improvements in our filaments, but in spite of the flourishing conditions of our factories just now, I could give many other illustrations of how we shall all suffer if we do not keep adding to our knowledge. Twenty years ago, when giving some lectures in Clerkenwell to workers in the then flourishing watch trade, I ventured to prophesy the decay of that trade. But I am afraid that the case of Jonah and Nineveh is the only one in which prediction of disaster led to reform. I venture on no prophecy therefore, because it might harden your hearts.

Much of the evil we suffer from is due to our average young men being pitchforked into works where they get no instruction, as soon as they leave school. If ordinary school education were worth the name, and if schoolmasters could be brought to see that we do not live in the fifteenth century, if boys were really taught to think for themselves through common sense training in natural science, things would not be so bad. But the average boy leaves an English school with no power to think for himself, and with less than no knowledge of natural science, and he learns what is called mathematics in such a fashion that he hates the sight of a mathematical expression all his life after.

And what is the result? English engineers do make

a wonderfully intimate acquaintance with the machines and tools that they work with, but when it comes to the manufacture of new things they do it by fitting and trying, by quite unnecessary expenditure of money through trial and error. A machine is made and tried and then another better one, until a good result is arrived at. And this method did well enough in the past and would do well enough in the future if only we had not to compete with foreigners who can really calculate. It is not all smoke; there is a real danger in this foreign competition unless we mend our ways. There is an absolute necessity for great change in English ways; but there are so many people interested in the maintenance of old methods of working; so many people who think they will lose their bread and butter if a change takes place; so much capital, scholastic and other, invested in our old machinery; that it takes a catastrophe to produce changes. Much of the strength and weakness of England has always lain in her conservatism. We have been talking of *standardisation* of machinery lately, so I may say that things have been standardised in England for a long time. Now to get all the good effect of standardisation it is occasionally necessary to go in for wholesale *scrapping*, and it is this scrapping part of the business that we dislike in England. We here all know that the District and Metropolitan railways might have been worked electrically years ago just as easily as they will be when we are allowed to begin upon them, but of course the scrapping of a lot of steam locomotives was a serious thing. The loss of experience to English electrical engineers, because of this hatred of scrapping, is leading to other incalculable losses. I understand that the whole generating and line plant—the whole machinery of the Boston tramways—has been scrapped several times since they first were driven electrically. Japan has scrapped all her old civilisation just as France did. During the century now dying Germany has made the most sweeping changes in her land and school legislation, and indeed in everything. England and Spain and China, how they differ in this respect even from England's own colonies.

Of course it may be said that English customs have grown during centuries; they are well tried and there is no pressing need for sudden alteration. I quite agree, but

unfortunately this very perfection and fitness of our customs have bred in us a want of flexibility, so that in cases where a sudden change is really necessary, we are disinclined to make the change merely because it is a change and for no other reason.

No one has ever heard me speak of the decadence of England. When the greatness and the wealth, the manliness and the strength, the healthiness and good life of England are shown forth to the as yet ignorant world in all their magnitude there will be some astonishment. But it is our duty to keep up our high standards. We must change what is bad when we know it to be bad, and not let bad things[1] continue to exist, parasitic growths, maintained because on the whole we are strong and healthy. You will perhaps think that this is a very serious exordium when I tell you that I have introduced it all on account of the state of mathematics in our profession. I feel a sort of degradation every time that I hear a successful, clever old member of this Institution sneering at mathematics. There is a plausibility about his statements; he himself has been very successful in life without much help from mathematics; but indeed his sneer is doing a great deal of harm to the younger members who admire his success, who forget that he has succeeded in spite of, and not because of, his neglect of mathematics.

Our knowledge of electrical phenomena must be quantitative to be of practical use; we must be able to calculate. Mathematics is the science of calculation, and we must therefore be able to employ, and we all do necessarily employ, less or more mathematics every hour of our professional lives. The draper and the grocer and the housekeeper merely need arithmetic. Everybody now knows some arithmetic. Everybody can add and subtract and multiply and divide, and keep accounts in some simple sort of way. This is due to the fact that arithmetic is no longer taught in the old Greek method with its twenty-seven independent

[1] Such as our wretched system of weights and measures. Oh young America and Australia, is it wise to waste a year of every child's life, and years of the life of every business man, merely because we do it in England? You get many of your pedagogues from us, and of course they say that without cwts., qrs., and lbs., and Latin declensions and Euclid, the mind cannot be trained. Do you believe them, or are you with open eyes making a great sentimental sacrifice?

characters (for our ten figures), the study of which required a lifetime, so that only old men could do multiplication, and they not only needed many hours to do one easy bit of multiplication, but declared that if the art were not practised every day it could not be remembered. Reading and writing and ciphering are now taught to everybody. It used to be that only learned men and philosophers could read, write, and compute. You will remember the charge that was brought against one of Shakespeare's characters, who was said to possess mere bookish theory without practical knowledge. "And what was he?" "Forsooth a great arithmetician." Nowadays, when everybody can compute, we should say of the possessor of mere bookish theory, "Forsooth he knows the calculus."

For in mediæval times things were taught in such a way that only a few men had a chance of knowing how to read, write, and cipher. We have been compelled to change all that, the pedagogue has by compulsion given up his mediæval methods of teaching in these things, although in all other matters he retains them. But a time has come when we see that ciphering is not enough mathematics for us to be familiar with, we need a little algebra, we need co-ordinate geometry, we need the differential and integral calculus. The pedagogue tells us that we must follow the orthodox course of study, which takes many years; and some of us, many of us, who have followed the orthodox method find that we have spent so much time and mental power upon it and its thousands of unnecessary tricks and contrivances and philosophy, that we can take in no more ideas. We cannot utilise our mathematics on engineering problems because we are too old and tired and *blasé* to comprehend these problems. Nevertheless we are the only people who know mathematics, and so we publish volumes of unmeaning and useless disquisitions on problems that we do not understand. Or we know just enough mathematics to be able to show our ignorance to experts, but quite enough to impress engineers with our knowledge; and we know just enough about engineering problems to show our ignorance to engineers, but quite enough to impress mathematicians, and what we publish is merely as the crackling of thorns under a pot.

As for the man who does understand electrical problems,

he remembers that there was a something called a study of mathematics at his school, that he did pass certain examinations with much difficulty and tribulation, that the subject had no real meaning to him even when he was supposed to know it, and he now hates the sight of anything that looks like mathematics.

I tell you, gentlemen, that there is only one remedy for this sort of thing. Just as the antiquated method of studying arithmetic has been given up, so the antiquated method of studying other parts of mathematics must be given up. The practical engineer needs to use squared paper. What is the use of telling him that he has taken an unauthorised way to the study of co-ordinate geometry, that he cannot approach it except through Euclid and modern geometry and geometrical conics and algebra and trigonometry. He says the youngest child can be made to understand diagrams on squared paper.

So again the idea underlying the calculus is one that every child, every boy, every man possesses and uses every day of his life, and there are useful methods of the calculus that might be taught quite quickly to boys, and which it would be a pleasure to boys and men to use continually in all sorts of practical problems, but of course the subject of the differential and integral calculus is one that must come at the end of a long course of what is to the average boy utterly uninteresting and unmeaning mathematics. Indeed, the average boy never reaches the subject, whose very names, differential and integral calculus, are enough to drive him frantic.

Yes, the schoolmasters say that we must follow the mediæval rules of the game, and all sorts of fine things are said about them, but as a matter of fact we only need to bring a little common sense to bear upon schoolmasters. At present most of us stick to our arithmetic as a safe and well-tried friend. We compute after the manner of the draper and grocer and housekeeper. In finding out what is the best size of conductor, or armature winding or core, or iron and winding of a field magnet, we calculate by mere arithmetic for one size and then for another; perhaps we have weeks of arithmetical computation before we find the right size of thing to use, and we cannot frame general rules. And some foolish person who knows a little mathe-

matics, works at the problem (as we ought to be able to do but are not) and he frames a general rule and we laugh at it, and sneer at mathematics because he has probably left out of account the most important consideration. We know that the result is wrong but we cannot say why it is wrong.

Then there are some far-reaching, labour-saving ideas that we simply cannot get into our heads at all, we cannot comprehend them. Am I sinning against the rule as to good comradeship which exists here if I say that some of us are ignorant of the most fundamental fact regulating economy in arranging sizes of conductors? Suppose we find the total cost of installing a conductor of a certain length, using one square inch section of copper. We do the same thing for other sizes, and we plot total cost and weight of mere copper on squared paper. I do not care what system we adopt if it is the same system for all sizes, and if we buy our materials from the same manufacturers and use the same kind of labour, our points will lie very nearly in a straight line on the squared paper. Hence increased cost will be proportioned to increased weight of copper, and, indeed, increased total cost will be like the mere increase in the cost of copper, taking a slightly higher price of copper per ton. Some of us, ignorant of the elementary mathematics involved in the problem, think that the mistake has been made of assuming that the cost of an installed conductor is merely the cost of the copper in it, and of course we must feel that it is too absurd a mistake not to be laughed over. With an elementary knowledge of mathematics our mistake would be impossible, and without such a knowledge the clever electrical engineer is constantly discovering mare's nests in the investigations which he criticises.

I know of long misleading accounts of the results of good experimental observations which might have been described in a few clear words by the aid of elementary mathematics. I know men who spend on a particular problem ten times the amount of worrying thought that would enable them to master the easy mathematics that includes all such problems. Quite recently one of our most eminent members declared to me that he had not really grasped the reason for small economy at a power station when there is a small load

factor until he studied the common sense mathematical form which has been given in a recent publication. And yet he is a man who has heard much, and read much, and talked much on this subject.

Every electrical engineer has a correct idea of how a transformer acts, or how the E.M.F. in one of the coils of an armature of a direct current or other generator, or, let us say, a rotary transformer, changes during a revolution, and how the E.M.F.s of all the coils are combined to produce currents in the external circuits. But through how much mathematical tribulation must most of us have passed from our state of ignorance to our present state of knowledge! It is no wonder that we are disinclined to the study of a new phenomenon which seems as if it might lead us through the like tribulation. The tribulation is least because it is suffered only once if we first learn the Calculus method which underlies all our work; it is greatest if we get it up in a completely new-looking form in every new problem. I speak now of what is most difficult in our study, for there is thought required in applying the Calculus method. Thus, for example, in multiphase work at the present time the best mathematicians wonder how it is possible for easy calculation to be made in such a subject. What we want just now is that an electrical engineer acquainted with three-phase current phenomena should be so much a master of ordinary easy mathematics that he has a chance of discovering a very simple way of putting the matter before us. At present calculation is easy but tedious, and, indeed, repellent; but I am perfectly certain that a competent man might quickly invent methods of calculation which are not only easy, but short and thinkable. Mathematicians with the requisite electrical knowledge, again, may be lacking in sympathy and humour. I know a book of more than three hundred large pages on ordinary alternating currents, and all the information in it is given far more simply in two pages of another book with which some of you are acquainted. Possibly, just now, mathematicians who are electrical and who have common sense have too much other work to do, and we must wait their leisure.

The fact is, mathematics ought to be the natural language of the electrical engineer, and at present it is a foreign language; we cannot read or write or think in it. We are

at the beginning of our development, like monkeys whose necessities have increased faster than their powers of speech.

Some of you are aware that a new method of teaching mathematics has recently been introduced by the ever-to-be-praised Science and Art Department in nearly all evening classes in science schools throughout the country.[1] I wish I could say that there was a prospect of its being introduced in all schools, for it seems to me that this would lead to the result that all young men entering works would be masters of that kind of calculation which is most important in electrical engineering; not merely a few men having this power, but the average men, just as average men can read and write.

I am addressing engineers, men who utilise the results arrived at by scientific workers, men whose profession is applied science. But surely if we are to apply the results arrived at by scientific men, if the laboratory experiment of to-day is to be our engineering achievement of to-morrow, we ought to be very much alive to all that is going on in the scientific world.

All men ought to be far more alive to the importance of scientific work. On the psychological side, it is perfectly exasperating to me to see how few are the men who know that Darwin has given a key to almost all the great philosophical problems of antiquity, and that there is a great mental development accompanying the more evident engineering development now going on in the world. Again it is the fault of our methods of education that all our great men, our most important, most brilliant, best educated men, our poets and novelists, our legislators and lawyers, our soldiers and sailors, our great manufacturers and merchants, our clergymen and schoolmasters, should remain so ignorant of physical science, the application of which by a few men not ignorant is transforming all the conditions of civilisation.[2] But of all men just think what it means for engineers to be ignorant of science, or neg-

[1] See summary of Lectures on Practical Mathematics; also the Science and Art Directory, and the Reports of Examiners on the Science Examinations of 1899 and 1900, all published by the Education Department, South Kensington, S.W. The reforms now advocated in mathematical and science teaching are all clearly described in a paper read before the Society of Arts in January, 1880.

[2] See articles in *Nature* of July 5th and August 2nd.

lectful of its new developments, and of all engineers think what it would mean if electrical engineers sinned in this way.

Except ours, all other branches of industry have taken thousands of years to grow. There were bridge and hydraulic and sanitary and harbour and river engineers in ancient Rome, and such engineers existed thousands of years before the first papyrus was written in Egypt. But no Assyrian tile or Egyptian hieroglyphic or relic from a tomb indicates that telephones or electric motors or electric lights existed before our time. No gradual improvement in our methods of conquering nature led up from small beginnings in our electrical engineering. Our profession has not grown during thousands of years of time like other professions. It has sprung suddenly, full grown, from the new spirit which is going to rule the souls and bodies of men, the spirit of research in pure science. The new spirit puts knowledge, mere knowledge of nature, as its highest aim. The scientific student knows that all sorts of good must come to mankind from his studies; all sorts of scientific knowledge are sure to be utilised by engineers, but in the pursuit of science the usefulness and utility of the result are of no importance. And are we—we who have received the first-fruits of the labours of scientific men, we the first-born spoilt children of the great parent of all that is to come, we who form the foremost files of the present time—are we going to turn upon our beautiful young mother and say she is useless and ugly, and she hinders our money-making, and that we are willing to kill her for the sake of the burial fee? Thank God that is the spirit of only a few of us. Have we not as an Institution gone to great expense in the publication of *Science Abstracts* in partnership with the Physical Society? That publication has been and continues to be of the very greatest value to all students of pure and applied science who read our language, for it tells them the results of all the scientific work now being done in all parts of the world. And even if some of us do not read that useful publication, do we not know that it is there to read if we like? Do we not know that it is a symbol of our redemption from the yoke of the Philistine? It is one of many signs that in answer to the question which I have asked in this address, we can truthfully say

that we are professional men, that our profession has promise of enormous expansion and improvement, and that we are not likely to become mere tradesmen.

I am afraid that you will think that I have a personal interest in putting before you the claims for consideration of the pursuit of pure science, because you know that I am trying to defend Kew Observatory from imminent danger. In truth I have no interest in this matter unbecoming a president of this Institution. For two years I have been trying to reason with traction engineers. Like many other electrical engineers these gentlemen desire to use uninsulated return conductors. If they do so near a magnetic observatory certain records of terrestrial magnetic disturbances are quite spoilt. At Potsdam this sacrilege has been forbidden. At Washington, Toronto, Capetown, and most other important places the magnetic records have already been rendered useless. Professor Rücker and I were asked by the other members of the Committee of the Royal Society which was in charge of the Kew Observatory to defend Kew, and with the help of Her Majesty's Treasury we thought we were able to insist upon the use of insulated returns in all undertakings authorised by Parliament where harm was likely to be inflicted on Government observatories. I may say that the scheme designed by Mr. Clifton Robinson for using an insulated return conductor in the working of the tramways of the London United Tramways Company, in consequence of our action, was a thoroughly good scheme which it gave one satisfaction to look at, not ugly and not expensive. It seemed to me a fit scheme for any tramway system, however complex, in which overhead conductors are used. You are aware that for an electric railway or for a tramway where an underground conduit is employed, it is in every way better, and it is in a large scheme actually cheaper to use an insulated return. We felt therefore very happy, for magnetic observatories seemed quite safe from interference. We were, however, mistaken, for the only clause which we have been able to get inserted in all Parliamentary authorisations of undertakings, leaves it to the Board of Trade to substitute other methods of protection than the insulation of the return conductors in cases where these other methods seem to be sufficiently good for the protection of laboratories and

observatories, and this is why the Board of Trade appointed the Committee which met on the 31st of October probably for the last time.

Professor Rücker, Professor Ayrton, and I have made many tests on the magnetic disturbances produced by tramways and railways, particularly by the Stockton tramways and by the Waterloo and City Railway, and we have had many meetings with the traction engineers, but nothing has yet been decided.

I mention this matter, which has given great anxiety to scientific men, because I am afraid that some of you may think when you hear of it that I have been acting against the interests of the electrical industry. I beg to assure you that I have been acting in your best interests. As an electrical engineer I ought surely to regret the use of uninsulated returns even if we leave Kew Observatory out of account. Suppose we do not now insulate our returns. Electricity will certainly return by gas and water pipes, and the amount of harm done to those pipes is merely a question of time. Because of the ignorance of legislators and gas and water companies, nothing is said just now, but will nothing be said at the end of ten or twenty years when pipes are found to be eaten away everywhere? And if by a slight increase of expense, or rather, as I think, actually no increase of expense, but merely a little increase in inventiveness and common sense on the part of electrical engineers, this evil may be entirely prevented, surely it is in the interests of all of us that insulated returns should be insisted upon. But even if we do not insist on insulating the returns in all systems, surely something may be said for the giving of this protection on lines near such a magnetic observatory as Kew. Even the magnetograph records now being made have been continuous for forty-five years, and if Kew is interfered with no sum of money can compensate for the interference; for if the Observatory were removed the future observations would have no link with the past.

An engineer in this room declared that it seemed to him an injustice to hamper the progress of electric tramways "for the sake of making observations that never have given, and never may give, to the world any important results." Now, it is not so much on account of Kew that

I object to this sort of observation, as for its general spirit of antagonism to scientific research.

There is no doubt that the answer to the old question which Gilbert might have asked three hundred years ago, "What is the cause of terrestrial magnetism?" is very jealously hidden from us by Nature. The earth probably contains much iron, but its great internal heat seems to forbid our imagining the iron to be magnetic. The assumption that a negative electric charge on the rotating earth will explain things, requires such an enormous charge that this assumption has been discarded. There are annual and diurnal variations of a fairly regular kind; there are storms which have some relation to the Aurora Borealis, to sun-spots and to earth currents. There are small sudden changes which seem to occur almost instantaneously all over the earth. Observations of these things may be useless from some points of view, but scientific men have been and continue to be willing to give up time and much money for this object. Utilitarians had to be cajoled through superstition to allow observations of the stars to be carried on in ancient times, and we have no such cajolery to offer. We simply say that it has been through this sort of useless-looking method of working that all our progress in science has come.

Engineers descended from men who sneered at Cavendish and Franklin and Volta and Oersted and Ohm and Faraday, are you who utilise the results of the work so sneered at and pile up fortunes in consequence of it, are you the men to sneer at and ridicule the scientific work of the present day because it seems to you useless?

Tell us a better method of observation; give us better suggestions as to what these magnetic phenomena may mean; but the past record of scientific observation enables us to laugh at you when you say that magnetic observations may never give the world any important results. Was Nature ever so open and yet so closed about a secret as she is about this one of terrestrial magnetism? Was there ever one whose revelation promised so much? How very little we know of electricity and magnetism! Does the mere motion of the earth, taking no account of electric charges at all, cause it to be magnetic? Almost anything is on the cards. Surely I need not appeal to your cupidity,

but it is quite possible that our knowledge of this secret may enable us to tap a tremendous store of Nature's energy.

Gentlemen, this is not a trades union, and it is not a society for the furtherance of pure scientific research, but it is a society of professional men who recognise the past services of scientific observers with gratitude and respect, and hope for greater ones in the future. And shall it be said of us that our gratitude is not greater than that of Judas, to whom indeed thirty pieces of silver was doubtless a large sum; that "we have given our hearts away a sordid boon;" and that as to our future hopes we are willing to sell our birthright for a mess of pottage?

ENGLAND'S NEGLECT OF SCIENCE

ARTICLE IN "NATURE" JULY 5, 1900

JUST before the first movement organised by Lord Roberts there was probably not one thinking person in England who was not ready to vote for an immediate change in all sorts of English methods of doing things. Consequently everybody was willing to listen to the advice of men who had for years been crying in the wilderness and prophesying disaster. Now, however, that we have worried through our military trouble, we shall probably feel so much ashamed of our intense fright as to put aside most of our desire for reform, and even to have less thought of it than before the war began. It is, therefore, the duty of those who have earned the right to a hearing to prevent the nation from sinking down into its sleepy acquiescence with old methods of working; and I am glad to see that Sir Norman Lockyer, in his speech at the Royal Academy dinner, referred to scientific education as a great, necessary line of defence of our country, secondary only to that of our naval and military forces. Again, two articles have appeared in the *Kölnische Zeitung* (March 10 and 11), which criticise our manufacturing and business and military want of method with an unsparing pen. The German writer and many English writers seem to think that we ought to copy Germany. Now I think that our reform must be far more thorough than anything which can be regarded as a mere copying of Germany; the methods which we adopt must be English methods, invented by Englishmen for Englishmen. If our methods are to help to lead in the future to a history comparable in glory with the history of the past, there must be a great common-sense reform in education in England from top to

toe. My friends, Profs. Ayrton and Armstrong, and I have so often pointed out the deficiencies of England in matters which we have carefully studied here and in foreign countries, that I hardly know whether an idea on this subject is my own or one of theirs; I do know, however, that we preach often on this subject, and that we never seem to be much attended to.

One thing that seems to be quite exasperating is that almost all the most important, the most brilliant, the most expensively educated people in England; our poets and novelists; our legislators and lawyers, our soldiers and sailors; our great manufacturers and merchants; our clergymen and schoolmasters, are quite ignorant of physical science; and it may almost be said that in spite of these clever ignorant men, and men like them in other countries, through the agency of a few men who are not ignorant, all the conditions of civilisation are being completely transformed. I do not merely mean here ignorance of the principles of science, I mean also ignorance of all those methods of working which come from experimental and observational scientific training. The great men go occasionally to popular scientific lectures (as they go to the Royal Academy), and they think that they comprehend something of the latest scientific discoveries because they have seen some fireworks and lantern slides; they are genial to scientific men when they meet them at dinner parties; but, in truth, scientific men are as much outside their counsels as sculptors or painters, or musicians or ballet-dancers. Among these great men a few visits to Albemarle Street are sufficient to create a reputation for science. I wish to show that this ignorance of our great men tends to create ignorance in our future leaders; is hurtful to the strength of the nation now, and retards our development in all ways.

These great men really direct the building of ships of war, and the creation of munitions of war; that is, they select the men who have to do these things, and they also lay down the unscientific rules which prevent their selected men from doing their work scientifically.

I will give an example. They order that the building of five line-of-battle ships shall be started immediately. The scientific constructor knows that he ought to throw

away—waste—£100,000 in making experiments to find out how the older type of ship may be greatly improved. But his superiors have made the rule that for money expended there must be something to look at. Hence no experiments may be made, and the constructor starts at once to expend five millions of pounds on building ships which are nothing like so good as they might be made.

Other examples. For many years huge guns were built of tubes. It was known to the few scientific men who can calculate about such things—the men who are never consulted—that it was not possible to turn and bore those tubes with the accuracy required by the theory. It happens that nature applies a correction to a wrong method of manufacture, and so these guns are not useless. It is quite well known that a little science and expensive experiment would cause the present wire method of manufacture of guns to be discarded for a simpler, quicker, better, cheaper system. The water-tube boilers, so numerous in our Navy, have proved as worthless as the best scientific men thought them from the beginning, and possibly now it is absurdly assumed that all water-tube boilers are useless. The construction of efficient submarine boats was possible thirty years ago. Many electrical and mechanical engineering appliances that might be very useful to an army or navy have never yet been tried under the direction of competent engineers. Above all—and this includes everything—men of scientific training are not chosen for the Government, civil, and naval and military posts where such training is necessary.

If our leaders were merely unscientific—if they were merely like Boers, and had no scientific knowledge—it would not be so bad, for they would probably appoint scientific men to posts in which a knowledge of physical science is needed, and they might accept the opinions of scientific experts. Even if they were like savage chiefs there would possibly be equal chances among all candidates for posts; but, unfortunately, it is as if our leaders possessed great *negative* knowledge of natural science, and as if a man's chances of being appointed to a scientific post, or of having his advice listened to, were in inverse proportion to his scientific qualifications.

Scientific men look around them and see that everything is wrong in the present arrangements, but they also

see that it is useless to give advice which cannot be understood by our rulers. And, indeed, I may say that when by accident a scientific man is appointed on a committee, there is a negative inducement for him to do anything.

Many men enter the services by examination. In some cases the examination is supposed to be in science. In truth, the scientific habit of thought, the real study of science, the very fitness of a boy for entrance to the service, would unfit him for passing these abominable unscientific examinations. For some posts—the Royal Artillery and Engineer services, for example—further scientific food is provided by the Government after a man enters. If one wishes to hear how evil this system of pretended education is, let him ask the opinion of some of the professors who are condemned to help in carrying it out. The whole system is foolishness from bottom to top, and the men prepared by the system cannot see how abominable it is even when they are afterwards trying to improve it.

But however harmful the present state of things may be for the Government services, I think that it is much more pernicious for the country at large. We see that the greatest intellects of our time have been developed through an education other than scientific; and as nobody can commend it for the mere knowledge given at school, it is commended for its importance in mental training.

It has been so often asserted by parrots, that many people do really believe that only mere mental training need be given until a boy is sixteen years of age. When one hears such a statement for the hundredth or thousandth time, he sometimes wonders if anybody ever does think for himself. Why, the early period of a boy's life is the time when he is not only getting mental training, but also collecting the largest part of all the knowledge that he ever will possess of the world into which he has come. So great is this stock of facts and theory, that when he looks back upon his life in old age he can hardly find that he has added much to it in the intervening years. Is he a musician in after life ? then he certainly learnt his skill, acquired his touch, trained his ear, and learnt thousands of airs in early youth. Is he a poet ? it is to his earliest efforts

that he looks back most fondly, and it was in his early youth that he learnt off by heart all the poetry that he really knows well in after life. He learns to read and write and cypher with ease and readiness; is this mere training of the mind? This craze for mind-training is really the worst thing that has happened to the hurt of children. It does not seem to be known to the mind-trainer that a child's mind grows most healthily when let alone—when the child is picking up knowledge in his own way. Give a boy a chance of seeing things for himself, and direct him as little as possible. Is there any kind of knowledge likely to be needed by him in after life? let him, when quite young, have some chance of picking up something of it for himself. He learns about people; he cannot help it, as he lives among people.

I take it that whatever kind of knowledge the race has been in the habit of picking up in youth is more easily picked up than any other by a boy himself. A boy takes to thinking for himself so naturally that the greater parts of some vile systems of education seem to be the destruction of this habit. Yes, education often means merely training a boy out of the way he *would* go into the way that we poor creatures think that he *should* go. And hence it is that the boy whose education is neglected, but who has chances of seeing things for himself, has often a much better chance in life than the well-trained prig.

Now there is a kind of knowledge greatly needed in life, that knowledge which is enabling us to fight with and use the powers of nature as they never were fought with or used before our time. The race is not accustomed to picking up this kind of knowledge, and so there is this one case in which artificial help to the child is absolutely necessary. Natural phenomena are complex; let him have a chance of using apparatus that will simplify these phenomena for him. It seems to me that natural science is almost the only study in which instruction from a father or teacher will not obstruct a boy's own natural method of study. And see how many ways of study are offered by it to a boy. Some of the sciences are greatly observational. If he is fond of abstract reasoning, he attacks things from the mathematical side. If he is fond of fireworks, he can attend popular lectures. If he loves to make and fiddle with apparatus,

and use it quantitatively, he has an altogether new method of study. He may choose which method he pleases; the study is utterly unlike a series of tasks; he does not get to think of a duty as something disagreeable; and, above all, he is encouraged to think for himself. Instead of constant correction, criticism, and reproof or punishment because he will think for himself, he is encouraged to consider that opinions which he disagrees with are to be criticised by him. If he feels that it is quite hopeless for him to follow abstract reasoning, say about a whole being greater than its part or the ratio of two incommensurables, or justification by faith, we reply to him—Yes, my boy, you have a good healthy mind like 98 per cent. of all English boys; it is quite impossible for us to make a seventy-year-old Alexandrian philosopher of you, thank God! time enough for you to do that for yourself when you have finished your educational course.

I say that this observational and experimental kind of study is almost the only one in which it is possible for a teacher to guide and instruct without doing harm—and it is very important that a boy's studies should be guided. Take the very clever boy who dislikes the study imposed upon him, and who takes earnestly to something else, his own choice, in which he has no guidance. See how he becomes a "crank." A man who might be of the salt of the earth if he could only co-ordinate his opinions with those of other people, a leader among men of thought; he loves to differ from all other people, and wastes a valuable life in disputation.

I know that many readers will find it difficult to consider this question; they will find it impossible to see things from a new point of view. As a rule a man has no point of view of his own, he never thinks for himself except about certain matters that only concern himself. Even a learned man thinks, not on the subject of his learning, but about his special methods of cataloguing his knowledge, and of course it is only from this that he can get any mental enjoyment. The dullest boy thinks a good deal, and even the average man, although thinking for himself has been repressed in him all his life. We ought to call all such people pedants, because they never really think about things of general interest to the world.

It is extraordinary how general is the impression of everybody that he really does think for himself and comprehends what he says. At the age of fourteen I wrote an excellent little essay on Chaucer ; I recollect now that my knowledge of Chaucer was confined to a few of the well-known extracts.

The opinions of educated young men change with the moon, or rather with the period of publication of the monthly magazines. A mathematical teacher uses the same fallacious logic in some demonstration year after year, and at length finds out his mistake from somebody else. Learning seems to destroy all power to think. From 500 A.D. to 1453 A.D. the scholars of Constantinople, with all the learning of Greece and Rome, produced not one original work.

I think that for a very clever boy any subject of study is good enough, although not so good as natural science. But Sanscrit, Chinese, or any other language and literature, or astrology or divinity, is just as good a medium as Greek or Latin, if all the best men of his own time happen to use the same medium, and if it enables him to come into mental contact with great men. But what of the other 98 per cent. of all boys—the average boys ?

The men who frame schemes of education really frame them for boys such as they themselves were. Anybody who cannot follow such a scheme is said to be stupid, and he is so often called stupid that he actually gets to think himself stupid. In this nineteenth century we do not wish, as in the time of Erasmus, to produce merely a few learned men. At all events, if parents pay largely for education, we do not think it fair to send back 98 per cent. of their sons with the contract unfulfilled on our part. Think of 100 boys being sent to a bootmaker who had only one kind of ready-made boot of one size. He sends ninety-eight of the boys back with feet so hurt by trying on that they can never wear anything but slippers all their life after ; he keeps their money, and compels the boys and their parents to take all the discredit of the transaction. Christ's curse is on the schoolmaster when he calls a boy a blockhead.

It is a very curious thing that when a boy has been called a dunce a number of times he actually gets to think himself a dunce, and in after life never blames his schoolmaster ; he has only praise for the system of education. Men who have never been able to do more than

quote tags from the Latin grammar, or to get beyond the Asses' Bridge in Euclid, are usually quite enthusiastic about the value of the orthodox education in the training of the mind, and so we find engineers and other illiterate persons advocating classical education. A donkey might just as well brag of the enormous advantage it was to him in having once been kept about a racing stable. But a much more curious thing is the praise given by clever mathematical physicists to the wretched system of teaching of Euclid which wasted their youth. A well-known and exceedingly able and ingenious scientific man praises the school teaching in physics and chemistry which he had as a boy from a certain master of his, and yet everybody who knew master and pupil knows that the pupil became a scientific man in *spite* of, and not through, the teaching of his master. Even if such clever men were right as to suitability of a system of training for themselves, they have no right to assume that it is right for the other 99 per cent. of boys at school.

Classical education gets all the credit that ought to belong to the other kinds of education that usually accompany it. A boy is at a good public school at which healthy, moral, manly training of all kinds is given to the usual manly type of boy. All the best masters are probably good in classics. The boy's own prizes are for classics, because there are not often scholastic prizes for anything else. Success in classics has been always put before him as the highest kind of success. The boys whom he worships are all good in classics. Of course, classics gets the credit for everything, including those things that are good in *spite* of the classics. Even good manners and tact and amiability, and I might almost say good batting and bowling and fielding, are thought to be due to the classics. The defenders of classics are numerous, and miss no chances. A scientific friend of mine, before a royal commission, commended the study of Greek, because the Greek alphabet is so much used in mathematics. Surely for such a purpose Chinese is ever so much more valuable, as there are many more letters. Again, it is said that the study of classics helps one greatly in the study of modern languages. These defenders forget that Russians and Japanese are the best of linguists, and yet they seldom learn any Latin or Greek. It is strange also to find so many English boys,

trained for years in Latin and Greek, who seem to find insuperable difficulties in learning a modern language. In any case I am inclined to think that there is too much inclination to force boys to learn modern languages. Some boys learn easily; for them the study may be good. Others learn with extreme difficulty. Had they not better study something else?

Everybody is aware of the enormous difficulty of introducing a new invention, however valuable, if it involves the "scrapping" of much existing machinery. Thus, electric methods of working the District Railway have not yet been introduced. The comfort of railway passengers everywhere is only slowly being attended to. For this reason electric lighting proceeded slowly in England and quickly in America.

Now all the machinery of a school head-master is fitted for the teaching of Latin and Greek. Every master is able to teach Latin well to clever boys, and everything good for mental training for clever boys in such teaching is well known to him. These men with capital so invested look with alarm on every new footing gained by science in schools, and with a wisdom gained by experience they introduce what *they* call science teaching, adopting methods which are such as can only disgust boys and their parents with the new study, and then they point to their want of success as a proof that the study of science affords no good education.

The prospect is very dismal; for the capitalists whom we fight against, whose interests we directly attack, are not only some of the very cleverest men of the country, but they have the ears of nearly all the other clever men.

In the time of Henry VII. the new learning fought and conquered the schoolmen, and England soon became covered with good grammar schools. Then mathematics came gradually in, fighting a hard fight till it has made its way and established itself—not on equality terms, but on terms of sufferance and recognition. To meet modern wants, to equip our men for the fight of to-day, we find that it is absolutely necessary to introduce the study of physical science, and lo! we have opposing us the combined forces of classics and mathematics, each with its own kind of weapon. The weapon of the mathematical pedant

is the more dangerous, for he says that he already represents science.

This teaching of pseudo-science in schools has created a manufacture of teachers. At all the universities we are now manufacturing science B.A.'s and B.Sc.'s because there is a new profession where money may be earned by the holder of such a title. This manufacture is called scientific education, and our real scientific men, pleased with the name, pleased at any experiment in scientific education, afraid that if they object there will be no education whatsoever in science, weakly give their countenance to it. To illustrate what I mean: At the greatest of our universities there is an examination in which experimental physics play an important part. A friend of mine coaches men for the examination. He tells them: "Listen to my coaching, read the books as I tell you, take care *not* to attend the physics laboratory. For in one day's reading you will get to know all that there is in thirty pages of the book; you may spend a month at the laboratory and you will have gained practically nothing to fit you for any possible kind of examination. The laboratory does not pay." Of course he is right, but if mere learning, if mere knowledge of certain facts, mere power to pass an examination, are what is aimed at, surely there is no scientific education here.[1] My friend asserts that the system by which he earns his living is abominable. The whole thing is so wrong that one wants an earthquake or a fire, one prays for wholesale destruction of the easily working examination machinery.

I remember teaching physics at a school in which the time for science was so limited that only one half-hour's lecture per week could be given to the best men in the school. There were about 100 of them, from the sixth and fifth forms. Some of them are now leaders of English thought. Well, they were actually examined once a fortnight—a paper examination, lasting an hour. Of course, they were not examined on the two lectures; they were really examined on two chapters of the text-book. I am told, and I believe, that in many of the best girls' schools science is supposed to be taught by a teacher reading things

[1] In Germany scientific book work is too much neglected in favour of a mere "Arbeit."

from a text-book, the girls taking notes. I should think it an excellent system if girls are required to pass the usual examinations.

Examinations are said to be in mechanics or dynamics, or mathematical physics, or mechanical or civil engineering. They are not; they are fraudulent substitutions of the stupidest kind of mathematics for these sciences.

Assume something or other to be true, that the coefficient of friction is constant, for example, or that a specific heat is constant, and, after covering the paper with easy mathematical exercise work, arrive at mathematic expressions which are as worthless as the mental training is bad. What a wonderful and useful weapon one possesses in mathematics! In the hands of a man like Rankine, or Kelvin or Maxwell, it removes mountains of difficulty. What a stupefying and useless weapon it is in the hands of a skill-less person who cannot think! And our examination systems and methods of education seem framed to cultivate one Kelvin to 10,000 of the pedantic non-thinking users of mathematics.

My theme has been the necessity for a complete change in our system of early education of everybody. The necessity is specially great in the case of the captains of industry. Many people think that if men are to be taught the scientific principles underlying the proper conduct of business or manufacture, it is only necessary to establish Technical Schools for them. When I was young I remember that there were many agricultural colleges in Ireland; they have all but one been failures. Why? Because the entering pupils were not fit to receive instruction. Instead of their having been prepared for instruction by their earlier education, this had done as much as possible to unfit them. We have just this sort of experience in our Technical Colleges. Great boys enter them, and it is difficult to find out what are the scraps of Euclid and mechanics known to these boys on which one has a chance of building technical instruction. It would almost be better to send such boys direct into practical work; they would probably do as well as the average workman; their fathers' influence and money would get them superior positions, and in a country like England they would do as well as their competitors in business. Yet there can be no doubt that it is

of the utmost importance to our country, if we are to retain our supremacy in manufactures, that all managers of works, and many of the superior persons employed in large works, should be scientific men, who are also well experienced in the applications of science to their particular industry. But this is not all. I have heard it said, quite truly, that for a great mechanical engineering works what is needed are well-trained managers and foremen, the best labour-saving tools, and an army of negroes as workmen. I am inclined to think that this statement is true; but there is something to be said for the employment of well-educated, intelligent workmen. First, because they are citizens of the country having votes; second, because I believe that all invention comes up from the common workman. These men make thousands of observations which somehow get to their superiors, and it is through these that inventions come unconsciously; an inventor makes use of ideas received from hundreds of men; the invention is truly his own, but he receives suggestions, unconsciously, from the men who work with their hands at the bench and in the machine shop. If then, I am right, the manufacturing country that depends upon a few good managers and an army of unintelligent slaves will fall as the Roman Empire fell.

Now a workman's intelligence must come through his trade, else he cannot be happy; and if he is unhappy in his trade he cannot be a good citizen or an efficient workman (from the above point of view). At present we pitchfork many boys into a factory, and depend upon the good nature of the workmen for their learning their trade. It used to be that a master taught such a boy his trade as a member of his own family. This personal teaching is no longer possible; but nothing has taken its place. Attendance of apprentices at evening classes after a hard day's work is quite out of the question for all but a small number of very clever young martyrs who sacrifice, not merely their own health and comfort, but the comfort of their families and their duties as citizens. I have myself publicly suggested several times a remedy for this state of things, which has been praised by competent persons,[1] but it seems to me that it is hopeless to expect any adequate

[1] See pp. 68–88 of this book.

remedy to be applied until the influential people of this country are made to see the gravity of the present position.

The great remedy for all our troubles lies in convincing all influential people in this country that we really must make great radical changes. I have known the subscribers of money to a large technical college in England (the members of its governing board) to laugh, every one of them, in private over the idea that such an institution could do any good to the trade of their town. How could it possibly do any good when there was such a spirit of unbelief among such people? We must create in England what already exists in Germany and France, and to some extent in America—a belief in the importance of scientific training everywhere. At present there is utter unbelief, and it is due to a bad system of education, which keeps everybody out of sympathy with everything scientific. It is terrible to hear our designers of bridges and steam engines and dynamos and great engineering schemes laugh at science and calculation, especially when one knows that foreign engineers are sneering at our best men; but it is well to know that, in spite of their laughter, our engineers are doing their very best to make use of all the true science that they have ever learnt; it is like gold leaf—very thin, but it serves a useful purpose. What they see clearly is the uselessness to God or man of such a so-called scientific training as they themselves had; they do not dream that there is a real scientific training possible by which useful mathematical and other weapons for solving all sorts of practical problems, handy to use and always ready, may become part of the mental machinery of the average man.

Four hundred years ago reading, writing, and cyphering were taught badly, and practical men looked upon them as things good to forget, things good for priests. If a layman could read or write, he was probably a useless person who, because he could not do well otherwise, took to learning. What a man learnt was clumsily learnt; if he learnt much, he was fit for nothing but learning; usually he learnt little with great labour, and made no use of it; therefore reading, writing, and cyphering seemed useless. Do they seem now so very useless; now that everybody can learn them fairly easily? It is not so easy now to say that a man is useless merely because he can read, write, or cypher. When I was

an apprentice, and no doubt it is much the same now, if an apprentice was a poor workman with his hands, he often took to some kind of study, which he called science. In fact, science got to be the sign of a bad workman. But if workmen were so taught at school that they all really knew a little science, science would no longer be laughed at. When a civil engineer or electrical engineer fails because he has no business habits, he takes to calculation and the reading of so-called scientific books, because it is very easy to get up a reputation for science. The man is a bad engineer in spite of his science, but people get to think that he is an unpractical engineer because of his scientific knowledge.

Germany has an enormous advantage just now in this, that all thinking Germans, all influential men, believe that their great success in commerce and manufacture has come through physical science. Every manager and foreman, every captain of any kind of industry in Germany and Switzerland, has passed with honour through the science classes of a great technical school. The money that used to flow towards religious institutions now finds its way towards the greater and greater development of scientific education, so that Germany is getting covered with universities of science.

The open-hearth process has enabled German ores of iron to be used in steel manufacture. The war-earthquakes have stirred up the German people to new life, have produced enthusiasm, and made all kinds of ambition respectable. Any one who knew such a tumble-down, poverty-stricken town as Hanover forty years ago would not recognise it now. There are miles of streets of the brightest shops in Europe ; at any time of the day or night one can read a small print newspaper in these streets ; the streets throng with traffic, and the electric tram-cars have extended the city far into the country ; and so it is in hundreds of towns, and manufactures flourish in thousands of places where the hare and partridge used to have the scenery to themselves. I do not think that the progress of Germany would have been half so rapid had it not been for the scientific education of the German leaders, but it is absurd to say that all this progress is due to science. The fact is that the whole world is developing its natural

resources. England had the start; every country that has coal and iron, or their equivalents, is competing with England. The countries of greatest natural resources can afford to neglect their scientific education longer than others; but, sooner or later, knowledge and method and character must tell. If countries are equal in their natural advantages, victory must remain with that one in which there is the best education.

I have hitherto been reviling only the higher education in England. Until quite recently there was no primary education to revile. Let me put before my readers a true contrast. In Scotland, at any time during the past one hundred years and more, if in the very poorest parish there was a boy of promise, a boy who showed a fondness for reading, for learning, for taking in what then and now goes under the name of education, a fondness for coming into contact with great minds through books—the success of that boy in life was absolutely sure. However poor his parents might be, however remote his humble home might be from civilisation, he was sent to the university, and got his chance. His nation gloried in his success, even if his own poor country had to be left by him for the richer field of England. Of all the great doctors and ministers and scholars of Scotch blood now to be found in London, only a very few can say that they were not exceedingly poor in their youth. Now contrast such a boy's chances with those of a clever English boy some years ago. Why, until the ever-to-be-praised Science and Art Department gave him a chance, a poor English boy, however promising, was compelled to eat his heart out in unavailing regret, was taught that it was a sin to think of bettering his condition, was taught that a decent education was as remote from him as from the cattle he tended.

I believe that this difference was due to the fact that in Scotland everybody thinks well of a good education, of knowledge, of mental power, because he himself can think, whereas in England education is looked upon with contempt, because there is not one labourer in a thousand who can think.

I do firmly believe that the Prince Consort saved this nation from utter defeat, and that if we are not yet to be defeated we must do as he would have continued to tell us

to do. Had he lived till now, this country would not merely have the beginnings of a development of art and science; it would be covered with educational institutions whose most important object would be scientific study, a secondary leaning to literature not being neglected. As it is, we have the merest dust of his mind expanded into a wonderful Science and Art Department, which is criticised adversely only by the very ignorant or the very prejudiced. Only people like myself, whose whole life has been a pæan of gratitude for what that department has done for me and mine, who have seen in thousands of cases that it has redeemed otherwise wasted lives with enormous benefit to our industries, are really in a position to imagine how much that great man might have done for us if he had lived.

For one thing, just as the Science and Art Department is the envy and admiration of foreigners; just as it is an English institution, made to fit England and no other country, so he would have developed scientific education in England on lines utterly different from the soul-destroying system of Germany or its imitation in America.

Consider a scientific German as you know him. Say that he is twenty-three or twenty-five years of age, and he is about to enter business. From the age of seven or less he has trudged to school, perhaps at seven o'clock in the morning, with a bag of books of half his own weight. He had a short interval for dinner, and went on to six o'clock at night. And he went on like that till now. There is no fact in all his school books that he has not heard a thousand times. He has had Goethe's maxims so drilled into him that he is "thorough" in every detail. I can imagine one Englishman in a hundred after such a training, patiently turning over the muck-heap of his knowledge; his eye would not gleam with any enthusiasm, but rather would glaze with envy and jealousy at the undeserved success of quite ignorant persons. And yet he would have knowledge, and know in his way how to use it; and it is because Germany has so many thousands of men trained in this way that she is certainly beating us to-day. They may be rather heavily loaded with learning, and I know that decently taught Englishmen who spent less than half the time at studies twenty times more interesting would beat them hollow in manufacture or research, would be the reverse of dull, and

would be good citizens; yet the Englishmen I want only exist as yet by ones and twos, and such Germans are numerous. But just think of it! Here we are, a hard-headed, obstinate, cool race of men, who have had no end of chances in our safe little island, whilst our enemies were fighting among themselves, with coal and iron and the influx of good foreigners to set us first in the new field, and we have more than half of all the wealth of the world, and all that is needed for our keeping our good things is that we should believe them to be possibly evanescent; that there really is a chance that some better equipped nation may take them away from us, and therefore that we ought to prepare ourselves to fight for them. We have many chances in our favour and we hardly use them; the competing foreigner is very energetic, and cultivates his smallest chances.

THE TEACHING OF MATHEMATICS

ARTICLE IN "NATURE," AUGUST 2, 1900

I THINK it very important to try to get a view of our system of teaching mathematics which is not too much tinted with the pleasant memories of one's youth. Like all the men who arrogate to themselves the right to preach on this subject, I was in my youth a keen geometrician, loving Euclid and abstract reasoning. But I have taught mathematics to the average boy at a public school, and this has enabled me to get a new view. I have seen faces bright outside my room become covered as with a thin film of dulness as they entered; I have known men, the best of their year in England in classics, lose in half an hour (as men did in the first day of slavery in old times) half their feeling of manhood; and I have known that, as an orthodox teacher of mathematics, I was really doing my best to destroy young souls. Happily, our English boys instinctively take to athletics as a remedy, and I know of nothing which gives greater proof of the inherent strength, in good instincts and common sense, of our race than this refusal to allow one's soul to be utterly destroyed. I have also mixed much with engineers, who really need some mathematics in their daily work, men who say that they once were taught mathematics, and I know that these men never use anything more advanced than arithmetic, and actually loathe a mathematical expression when it intrudes itself into a paper read before an engineering society. Of all branches of engineering, electrical engineering relies most upon exact calculation. Well, the average electrical engineer in good practice would rather work a week at many separate arithmetical examples than try for an hour to get out the simple algebraic expression,

which includes all his week's results and much more. Yet he has passed perhaps, certain rather advanced examinations in mathematics. Furthermore, those engineers who can most readily apply mathematics to engineering problems, almost invariably descend to the position of teachers and professors in schools and colleges, and they seem to lose touch completely with the actual life of their profession.

I have studied these phenomena very carefully, and I affirm that they are directly traceable to the absurd thing called mathematical teaching in schools and colleges.

The framers of educational methods took in their youth to abstract reasoning as a duck takes to water, and of course they assume that a boy who cannot, in one year, understand a little Euclid must be stupid. In truth, it is a very exceptional mind, and not, perhaps, a very healthy mind, which can learn things or train itself through abstract reasoning; nor, indeed, is much ever learnt in this way. Do we philosophise about swimming before we know how to swim; or about walking, or jumping, or cycling, or riding a horse, or planing wood, or chipping or filing metals, or about playing billiards or cricket? Is it through philosophy that we learn a game of cards, or to read or to write? No; we first learn by actual trial; we practise as our mind lets us; we philosophise afterwards—perhaps long afterwards. Then if we are too clever or stupid, we insist on teaching a pupil from the point of view which we have at the end of our studies, and we refuse to look at things from the pupil's point of view.

What a natural but ghastly statement the boy made who said: "Yes, Euclid and Xenophon, the beasts, wrote books for the third and fourth forms!" It is even a ghastlier notion that the jokesomeness of a philosopher, the unessential fringe of a subject, often becomes the soul-destroying weary, worrying study of a schoolboy.

In a short article I shall not attempt to put forward my views as to how mathematics ought to be taught; I have published some of them in a summary of lectures on "Practical Mathematics," published by the Science and Art Department, and in my "Calculus for Engineers."

We let a Board School boy jump over all the ancient philosophy of arithmetic, with its twenty-seven independent Greek characters (for our ten figures), the study of which

required a lifetime, so that only old men could do multiplication, and they not only needed many hours to do one easy bit of multiplication, but declared that if the art were not practised every day it could not be remembered. Why not also let a boy jump over all the Euclidian philosophy of geometry, and assume even the forty-seventh proposition of the first book of Euclid to be true? Why not let him replace the second and fifth books of Euclid by a page of simple algebra, and give him much of the sixth book as axiomatic? If you must insist on abstract reasoning, you had better remember that nothing is really axiomatic; but any well-established truths may be looked upon as fundamental or axiomatic, and a system of abstract reasoning may be founded upon them. At present a man at Cambridge finishes just where the really interesting and useful part of mathematics begins. There would not indeed be much difficulty in framing a course in which he would begin his studies where the studies of good mathematicians now end. This has been tried and proved successful. The present rules of the game are really a little too absurd. A difficult vector subject like geometry must be studied before algebra. Simple exercises on squared paper, well within the capacity of even illiterate persons, must not be approached until one has wasted years on higher algebra and trigonometry and geometrical conics, because they belong to the subject of co-ordinate geometry. It is assumed that it is not until after co-ordinate geometry is thoroughly studied that a man can take in the idea which underlies the calculus, an idea which is possessed by every young boy with absolute accuracy, and by every healthy mind.

Some friends of mine assert that no boy or man ought to be allowed to use logarithms until he knows how to calculate logarithms. They say this, knowing that the calculation is a branch of what is called higher mathematics, and that the average schoolboy, after six years at mathematics, finds it hopeless to even begin the study of the exponential theorem. It is a hard saying! It is exactly like saying that a boy must not wear a watch or a pair of trousers until he is able to make a watch or a pair of trousers. I am an advocate for the use by all students of all appliances which may be useful to them, whether made by tailors, or watchmakers, or instrument-makers, or builders, or pure mathematicians. We need

not believe a craftsman when he tells us that we cannot utilise his results without practising his trade. Nevertheless, it is good to be able to do some things for one's self, such as sewing on buttons, or using the lathe or a blowpipe, or the development of a little mathematics. If readers will refer to the above-mentioned *summary* they will see that I consider a good system of mathematics teaching of fundamental importance in the education of all men.

I must not dwell any longer on the imperfections of the existing system, but I hope that even readers who do not quite agree with me that much of the sixth book of Euclid ought to be regarded as axiomatic, will agree that what we usually call arithmetic is useless. For races not troubled with our abominable system of weights and measures, the whole of arithmetic consists merely of multiplication and division. To them a decimal is no more difficult to understand than an ordinary number. It is supposed that an English boy understands at once the meaning of 4,590,000 or 4,590, or 459, but that such a number as 45·9, or ·459, or ·00459 is beyond his comprehension. I say, that this is a difficulty artificially maintained by our stupid methods of teaching. Like the rest of our stupid methods, it is due to our unscientific ways of thinking. Because the embryo passes through all the stages of development of its ancestors, a boy of the nineteenth century must be taught according to all the systems ever in use and in the same order of time. The decimal system of stating numbers is 700 years old in Europe, but it was not till 280 years ago that Napier invented the use of decimals and the decimal point. Think of compelling all emigrants to pass to America through Cuba, because Cuba was discovered first. Think of making boys learn Latin and Greek before they can write English, because Latin and Greek were the only languages in which there was a literature known to Englishmen 450 years ago.

Again, the ingenious teachers of last century incorporated every kind of arithmetical example in a book and called each kind by a slang name—practice, interest, discount, tare and tret, alligation, position, &c., and we must teach exactly as they did. I do not mind retaining the buttons at the back of my coat; many useless ancient ceremonies may still be practised, and I shall not object.

I can even admire them, but the unscientific waste of the valuable youth of millions of our people, now that we are face to face with nations who are determined to destroy England through commerce and war, is so abhorrent to me that I cannot think of it with patience. It is not merely in arithmetic and geometry, but in the higher parts of mathematics that this waste goes on. Newton employed geometrical conics in his astronomical studies, and mechanics was developed; and therefore it is that every young engineer must study mechanics through astronomy, and he dare not think of the differential calculus till he has finished geometrical conics. The young applier of physics, the engineer, needs a teaching of mathematics which will make his mathematical knowledge part of his mental machinery, which he shall use as readily and certainly as a bird uses its wings; and we teach him in such a way that he hates the sight of a mathematical symbol all his life after.

It is just as in classics. Ask the average man if he ever reads anything now in Latin or Greek; ask him about anything to which he devoted ten years of his study at school, and he will answer that the only men he knows of who read the classics are a few famous scholars and the cads who read with delight cribs of the *Odyssey* and the *Iliad* just as if they were novels, because they never had the advantage of a classical education. But, of course, his mind was trained, he can always say that.

The authorities of the Science and Art Department recognise that apprentices and others attending evening classes may possibly benefit by a course of study very different from what is necessary if students are being prepared for university and other examinations. Hence, in addition to their very complete orthodox courses of instruction, they recognise the new method of study, the most elementary part of which is beginning to get crystallised in the following syllabus. There is also an "Advanced" syllabus, which is too long to be published here.[1] I would advise interested persons to write to the Department for copies, and also for the report on the result of last year's examination, as well as for copies of the examination papers and of the above-mentioned summary.

[1] I now publish both.

I venture to hope for criticism of this syllabus—first, from men like my Cambridge friends, who are quite sympathetic, but who think the method one fit for evening classes only; second, from men who think with me that the method is one which may be adopted in every school in the country, and adopted even with the one or two boys in a thousand who are likely to become able mathematicians; third, from other men. Whatever be the point of view of any critic, he must surely feel that exhaustive criticism is important, for there are many large technical schools in England in which the method has already been adopted, the orthodox system being quite given up. I have been informed that the method is spreading rapidly in Germany also. I can already see from the exceedingly interesting examination results that crystallisation is proceeding rapidly, and if criticism is to be of value, now is the time for it. I hope also that the seemingly bumptious manner in which I criticise orthodox methods of teaching will not induce contemptuous indifference in men of thought. I hold a brief in the interests of average boys and men; my strong language and possible excess of zeal are due to the fact that nearly all the clever men have briefs on the other side.

PRACTICAL MATHEMATICS

Elementary Stage.

ARITHMETIC.—The use of decimals; the fallacy of retaining more figures than are justifiable in calculations involving numbers which represent observed or measured quantities. Contracted and approximate methods of multiplying and dividing numbers whereby all unnecessary figures may be omitted. Using rough checks in arithmetical work, especially with regard to the position of the decimal point.

The use of $5 \cdot 204 \times 10^5$ for 520400 and of $5 \cdot 204 \times 10^{-3}$ for ·005204. The meaning of a common logarithm; the use of logarithms in making calculations involving multiplication, division, involution and evolution. Calculation of numerical values from all sorts of formulæ.

The principle underlying the construction and method of using a common slide rule; the use of a slide rule in making calculations. Conversion of common logarithms into Napierian logarithms. The calculation of square roots by the ordinary arithmetical method. Using algebraic formulæ in working questions on ratio and variation.

ALGEBRA.—To understand any formula so as to be able to use it if numerical values are given for the various quantities. Rules of Indices.

Being told in words how to deal arithmetically with a quantity, to be able to state the matter algebraically. Problems leading to easy equations in one or two unknowns. Easy transformations and simplifications of formulæ. The determination of the numerical values of constants in equations of known form, when particular

values of the variables are given. The meaning of the expression "A varies as B."

Factors of such expressions as $x^2 - a^2$, $x^2 + 11x + 30$, $x^2 - 5x - 66$.

MENSURATION.—The rule for the length of the circumference of a circle. The rules for the areas of a triangle, rectangle, parallelogram, circle; areas of the surfaces of a right circular cylinder, right circular cone, sphere, circular anchor ring. The determination of the area of an irregular plane figure (1) by using a planimeter, (2) by using Simpson's or other well-known rules for the case where a number of equidistant ordinates or widths are given, (3) by the use of squared paper whether the given ordinates or widths are equidistant or not, the "mid-ordinate rule" being used. Determination of volumes of a prism or cylinder, cone, sphere, circular anchor ring.

The determination of the volume of an irregular solid by each of the *three* methods for an irregular area, the process being first to obtain an irregular plane figure in which the varying *ordinates* or widths represent the varying *cross sections* of the solid.

Some practical methods of finding areas and volumes. Determination of weights from volumes when densities are given.

Stating a mensuration rule as an algebraic formula. In such a formula any one of the quantities may be the unknown one the others being known.

USE OF SQUARED PAPER.—The use of squared paper by merchants and others to show at a glance the rise and fall of prices, of temperature, of the tide, &c. The use of squared paper should be illustrated by the working of many kinds of exercises, but it should be pointed out that there is a general idea underlying them all. The following may be mentioned :—

Plotting of statistics of any kind whatsoever, of general or special interest. What such curves teach. Rates of increase.

Interpolation, or the finding of probable intermediate values. Probable errors of observation. Forming complete price lists by shopkeepers. The calculation of a

table of logarithms. Finding an average value. Areas and volumes as explained above. The method of fixing the position of a point in a plane; the x and y and also the r and θ, co-ordinates of a point. Plotting of functions, such as $y = ax^n$, $y = ae^{bx}$, where a, b, n, may have all sorts of values. The straight line. Determination of maximum and minimum values. The solution of equations. Very clear notions of what we mean by the roots of equations may be obtained by the use of squared paper. Rates of increase. Speed of a body. Determination of laws which exist between observed quantities, especially of linear laws. Corrections for errors of observation when the plotted quantities are the results of experiment.

In all the work on squared paper a student should be made to understand that an exercise is not completed until the scales and the names of the plotted quantities are clearly indicated on the paper. Also that those scales should be avoided which are obviously inconvenient. Finally, the scales should be chosen so that the plotted figure shall occupy the greater part of the sheet of paper; at any rate, the figure should not be crowded in one corner of the paper.

Geometry.—Dividing lines into parts in given proportions, and other illustrations of the 6th Book of Euclid. Measurement of angles in degrees and radians. The definitions of the sine, cosine, and tangent of an angle; determination of their values by graphical methods; setting out of angles by means of a protractor when they are given in degrees or radians, also when the value of the sine, cosine, or tangent is given. Use of tables of sines, cosines, and tangents. The solution of a right-angled triangle by calculation, and by drawing to scale. The construction of a triangle from given data; determination of the area of a triangle. The more important propositions of Euclid may be illustrated by actual drawing; if the proposition is about angles, these may be measured by means of a protractor; or if it refers to the equality of lines, areas, or ratios, lengths may be measured by a scale and the necessary calculations made arithmetically. This combination of drawing and arithmetical calculation may be freely used to *illustrate* the truth of a proposition.

The method of representing the position of a point in space by its distances from three co-ordinate planes. How the angles are measured between (1) a line and plane, (2) two planes. The angle between two lines has a meaning whether they do or do not meet. What is meant by the projection of a line or a plane figure on a plane. Plan and elevation of a line which is inclined at given angles to the co-ordinate planes. The meaning of the terms "trace of a line," "trace of a plane."

The difference between a *scalar* quantity and a *vector* quantity. Addition and subtraction of vectors.

CALCULUS.—Slope of a line; slope of a curve at any point in it. Rate of increase of one quantity y relatively to the increase of another quantity x; the symbol for this rate of increase, namely $\frac{dy}{dx}$; how to determine $\frac{dy}{dx}$ when the law connecting x and y is of the form $y = ax^n$. Easy exercises on this rule.

In setting out the above syllabus the items have been arranged under the various branches of the subject.

It will be obvious that it is not intended that these should be studied in the order in which they appear; the teacher will arrange a mixed course such as seems to him best for the class of students with whom he has to deal.

ADVANCED STAGE.

The instruction given in the Advanced Stage should include a revision of some of the more important portions stated in the syllabus for the Elementary Stage. In addition, the following should be considered :—

More practice in the use of logarithms and other mathematical tables for finding numerical values from more difficult or more complicated formulæ. More attention to *method* in carrying out computations of all kinds. The use of approximate formulæ such as—

$$(1 + a)^n = 1 + na \text{ when } a \text{ is small compared with } 1.$$

Rules in Arithmetic (as of compound interest, &c.) and in Mensuration, stated as algebraic formulæ. Any one of the quantities in a formula may be the unknown one.

Practice in the simplification of algebraical expressions. Solution of equations, and problems leading to equations. Resolution of a fraction into partial fractions.

TRIGONOMETRY.—How to find the values of the sine, cosine, and tangent for angles greater than 90°; complementary and supplementary angles.

The fundamental relations, such as $\sin^2\theta + \cos^2\theta = 1$.

The fundamental formulæ for the sine and cosine of the sum or difference of two angles, that is—

$$\sin(A + B) = \sin A \cdot \cos B + \cos A \cdot \sin B$$

and the other similar ones. Formulæ derived from the above, such as those for the sum and difference of two sines or cosines, and those which connect an angle and the double angle.

The sine rule, or $\frac{\sin A}{\sin B} = \frac{a}{b}$ in triangles. Also the rule $c^2 = a^2 + b^2 - 2ab \cos C$.

The expression for the area of a triangle, having given two sides and the included angle, $\frac{1}{2} ab \sin C$.

The truth of such formulæ ought to be illustrated numerically and graphically by taking numerical values of the quantities, but the proofs are also supposed to be known to the candidates.

MENSURATION.—Guldinus' Theorems relating to areas and volumes of surfaces and solids of revolution. Exercises on the area of a segment and sector of a circle, the area of the surface of a sphere between any two parallel planes; approximate rules for length of a circular arc.

Finding centres of gravity using squared paper.

USE OF SQUARED PAPER.—The plotting of functions including such as $y = ax^n$; $y = ae^{bx}$; $y = a \sin(cx + d)$; $y = ae^{bx} \sin(cx + d)$.

Having given observed values of two varying quantities which are known to follow one or other of laws like $pv^n = c$, $y = a + bx^2$, $xy = bx + cy$, to find the probable values of the constants.

When two varying quantities are known to follow a given but somewhat complex law, to determine a simpler law which, between certain limits, will give values approximating to the correct ones.

Solving equations by the use of squared paper.

Maximum and minimum problems.

GEOMETRY.—How the position of a point in space is defined by its rectangular co-ordinates x, y, z, or by its polar co-ordinates r, θ, ϕ; the relations between x, y, z and r, θ, ϕ.

Determination of the three angles α, β, γ which a given line makes with the three co-ordinate axes; the relation—

$$\cos^2 \alpha + \cos^2 \beta + \cos^2 \gamma = 1.$$

Determination of the angles between a given line and each of the co-ordinate planes.

When a plane is given by its traces, to determine its inclination to each of the three co-ordinate axes and planes.

The above may be treated analytically or graphically.

Representation by its projections on the three co-ordinate planes, of a line whose position and real length are given.

Determination of the angle between two given lines; the angle between two planes whose traces are given. Represent by its projections the line of intersection of two planes whose traces are given.

VECTORS.—The scalar product and vector product of two given vectors with illustrations. Vector Algebra.

RATES AND SUMS.—Rate of increase of one quantity relatively to that of another; approximate methods of calculating a rate of increase as, for example, in the case where simultaneous values of two varying quantities have been observed experimentally, or by finding the *slope* of the curve obtained by plotting such values.

The term "differential coefficient" as applied to a rate of increase; and the symbol for it, namely $\frac{dy}{dx}$, where y and x represent the two varying quantities.

Rules for finding the differential coefficient of y with respect to x, that is, $\frac{dy}{dx}$, when y and x are related in the following ways :—

$$y = ax^n\,;\ y = ae^{bx}\,;\ y = \sin x\,;\ y = \cos x\,;\ y = a\sin(bx + c);$$
$$y = A \log(x + a).$$

The study of these functions.

Calculation of maximum and minimum values.

Integration regarded as the inverse of differentiation, or as a process of summation ; the symbols $\int y \,.\, dx$ and $\int_a^b y \,.\, dx$; rough methods of finding an approximation to $\int_a^b y \,.\, dx$ when numerical values of y and x are known.

The expressions for the following integrals—

$$\int ax^n\, dx\,;\ \int ae^{bx}\, dx\,;\ \int \frac{A}{x + a}\, dx\,;$$
$$\int A \sin(ax + b)\, dx\,;\ \int A \cos(ax + b)\, dx.$$

Illustrations of the use of the calculus.

ADVICE TO MECHANICAL ENGINEERING STUDENTS ABOUT TO LEAVE THE FINSBURY TECHNICAL COLLEGE[1]

REPRINTED FROM "THE ENGINEER," JULY 13, 1889

AT the close of the Session of the Finsbury Technical College, Professor Perry, F.R.S., delivered an address to his second-year students and some of their parents, to the following effect:—

A question of peculiar importance to you mechanical engineering students is what you are to do when you leave college. The subject is a hackneyed one to me, for I have given advice to students in various previous years; but for you it is very different. You are going to have a perfectly novel experience, and the present is one of the most serious times of your lives. As I look at your faces I think of the many who have left me since I began to teach about twenty years ago. I have heard that some of my old students are now cab-drivers, some have occupied legislative and administrative positions in this and foreign countries. Some are in Japan or India, in charge of large engineering works. Some of my old Finsbury students, young as this College is, have already made their mark, others are already showing that they are "duffers." A good mechanical engineer must be a fairly good workman with his hands, but it is of even more importance that, whether or not he has manual skill, he shall at an early age have worked side by side in the shops with men as one of themselves, gaining slowly or quickly, as his sympathy and quickness may have determined, that peculiar kind of experience which is not to be obtained in any other way, and without which a manager of

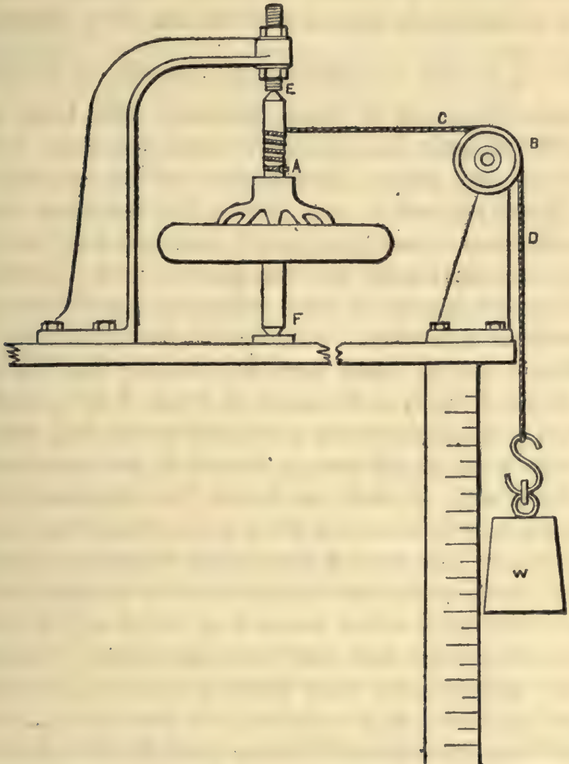
[1] I am sorry to think that this is the only one of my annual addresses which has been preserved.

works is a mere Molesworth's pocket-book bound in calf. How much more than a mere workman he can become depends partly on his having had a decently good liberal education; greatly upon his having had a good scientific education in mathematics, physics, and mechanics, and upon his power of drawing, but probably most of all upon his powers of imagination, his originality, his common sense, which lead to a cautious but respectful appreciation of new ideas. I admire very much the man who believes so much in the mathematical theories given in books that he is ready with a formula at every little difficulty in his practical work—I admire him, but I am not always able to imitate him. Indeed, you will find that one of your great troubles will be that you will dissociate your theory from your practical work. However much you may believe in theory, you will often forget all about it or refuse to apply it, except when you are writing or reading. This is often due to the fact that you are aware of the incompleteness of mathematical theories in general, and it will gradually come home to you that the good mechanical engineer must have a far more extended theory about mechanical things than is given in any book, or than he himself can formulate.

Nowlet us consider how you are equipped for entering the profession. About half of you can use the differential and integral calculus; you all have practical knowledge of what is meant by a differential coefficient; not one of you would, I am sorry to say, be able to satisfy an ordinary mathematical examiner, but I think that such knowledge as you have is handy; it is a tool kept for use rather than show. Remember, however, that it is not possible for you to become too good a mathematician. Your drawing is excellent. Even at the end of your first session you could all turn out drawings as different as possible from "drawing-class" drawings; not one worthy to be framed and admired by your fond female relations; but only a very experienced man could have told that your drawings had not come from a real drawing office. You cannot yet do any designing; that can only come after you have had the workman's experience. But if I asked one of you to go to Glasgow to sketch a machine he would come back with every dimension right, not one missing, and he could turn out working drawings of that machine with all its details, in such a style that

the men in a shop would respect them and think them made by a regular well-paid draughtsman.

Of your work in practical geometry, chemistry, physics, and modern languages I need not speak. Let us consider your equipment in regard to mechanics. You have had lectures, numerical exercise work, and laboratory work on this subject. Among the numerous investigations which



INSTRUMENT FOR MEASURING THE ENERGY OF A FLY-WHEEL

you have made in the laboratory it is difficult to choose one rather than another to illustrate my system. Let us take this well-used fly-wheel. The M of a fly-wheel, multiplied by the square of its number of revolutions per minute, gives the kinetic energy stored up in it in foot-pounds. You are asked to measure experimentally the M of this fly-wheel; the loop at the end of a cord goes over the pin A on the spindle, and is wrapped n times round the spindle, then goes

over the pulley B, and has a weight W at its end. At time 0 the wheel is let go; in t_1 minutes—carefully observed—the cord drops off; in t_2 minutes from starting the wheel has been brought to rest again by friction. The weight W lb. multiplied by the height in feet through which it has fallen gives the energy stored up in the wheel at time t_1, so that if the speed were then known M could at once be calculated. But as we have no speed indicator, we take it that the motion is uniformly accelerated till the cord drops off, or we take $2\frac{n}{t_1}$ as the revolutions per minute at the time t_1. The corrections are of more interest. We have first to deduct the kinetic energy of W when the cord drops off. Then we must make experiments on the friction of the pulley B, for the pull in the cord at C is less than what it is at D, and these experiments are themselves very interesting, for they are made with the two parts C and D vertical, so that the parallelogram of force principle must be brought in to make them available. Next we correct for the friction at the pivots E and F. And here we observe that the average speed from t_1 to t_2 is the same as from 0 to t_1, and hence that from t_1 to t_2 the motion is uniformly retarded, and hence that there is as much energy wasted in any one revolution as in any other. If, then, we know the number of revolutions from t_1 to t_2, we know the energy wasted in one revolution, and we can correct for friction before the cord drops off; and so we make one correction after another, and there is hardly any limit to the amount of ingenuity required, as the corrections get less and less important. I remember that four grey-headed men worked together once at this piece of apparatus in the evening for five weeks, and when at length they had satisfied themselves with their corrections they had practically used many times every important principle of mechanics, and they had acquired a handy working knowledge of all these principles.

You will perhaps allow me to refer to one other illustration of my system. Thirty of us have a field-day with the engine which drives the large dynamo-machine lighting the College. Each of you has on more than one occasion acted as stoker and engine-driver, as oiler and tester of machinery of this College, lighting fires, taking indicator diagrams, weighing coals, opening and closing cocks, from

seven in the morning to ten at night, so that the engine-room is well known to all of you. We have three different steady loads during the trial. We divide into groups, and one of each group ceases to take certain kinds of observation every ten minutes, and removes to another job. Each student takes the time at which he makes an observation. These observations are—taking indicator diagrams, checking the speed indicator, taking the temperature of the feed-water, taking the quantity of feed-water by the meter, whose accuracy you had tested already, taking the actual horse-power passing through the dynamometer coupling on the shaft, whose accuracy some of you have measured ; taking the boiler pressure, the pressure in the valve chest, the vacuum gauges at the vaporising condensor on the roof and in the engine-room, the quantity of coals used, the calorific power of the coals having already been measured by you, and making other mechanical measurements ; measuring also the electrical horse-power given out by the dynamo, the number of electric lights which are glowing, &c.

Each of you reduces his own observations in the way already described to you. He finds his indicated horse-power, the feed-water per hour per indicated horse-power, the water per hour shown by his diagrams per indicated horse-power, and so on ; and when we have gathered all our observations into a great table, and each of you has seen with certainty how the total energy of the coal is distributed —so much up the chimney, in the steam jacket, in condensation in the cylinder, to the condenser, in friction in the engine, &c., &c.—he has obtained a practical knowledge of the steam engine which no amount of reading or listening to lectures could possibly supply.

I need not apologise to you for showing you how you are equipped. I want to impress upon you the value of the training you have had. Like other men, you can make calculations from formulæ ; but just think of the results of the experiments made by you on friction at different speeds, and notice the light which they throw upon the insufficiency of the formulæ which you must employ in making calculations. They not only do this, but they give you courage to make calculations, for you know now the extent of your ignorance and knowledge.

Some of you will, I think, become eminent in the mathe-

matics of engineering. I am sorry to say that many of you will fail to pass our examinations, and will not obtain the College certificate. Now that you are about to leave us, I may tell you that this certificate business does not matter so very much after all. You have all done your best, I think, and I have nearly as much sympathy with those who fail in examinations as with those who pass. I have had a large experience of men, and know that the race is not always to the apparently swift. There is a crucial question to be asked you. Do you like mechanical engineering in any of its aspects? Do you love to fiddle with mechanical things? Have you been put into this line by your parents, or do you like it for itself? Would you prefer going into the Church, or into a bank, or have you a hankering after law or doctoring? If so, now is the time to act upon that instinct; it is not too late; your education will not be wasted. However high up you may have been in an examination list, give the thing up! If, however, you like mechanical engineering, stick to it, notwithstanding any failure to pass an examination. Far be it from me to disparage those who pass examinations well—you know that I honour them highly—but they will yet find out that some of their contemporaries whom they look upon as "duffers" will be magically successful as engineers if they love their profession, and bring to it the common sense in which few Englishmen are deficient.

Hitherto you have been learning how to learn your trade. You have been learning the principles underlying a trade, but not the trade itself. You have, it is true, acquired a considerable amount of skill. Some of you can chip and file and scrape as well as any fitter in the country. Some of you can set a bit of work in the shaping machine as skilfully as any man. But all this training has been given you that you may learn to be a good workman in three years instead of seven.

Under the apprenticeship system of the Middle Ages a man learning his trade lived with his master almost like a servant; it was a friendly kind of relationship, and the master taught him his whole trade; probably in the end he married his master's daughter and succeeded to the business. That system is now disappearing, except in some few parts of England; at Sheffield, for instance, it still survives

in a very modified form. But, of course, when a master has many hundreds of hands at the present day, a boy is pitchforked into the works, and it is nobody's duty to teach him anything. I wish I had time to dwell on my own experience as an apprentice, rising gradually from three shillings a week in the first year, as duly noted in my indentures, by a shilling a week for seven years. Suffice it to say that I do not see why, with your training, you should not gain in two and a half or three years the skill and knowledge which the ordinary untrained boy, with much want of self-respect, and very often with harsh treatment from everybody, takes seven years to acquire.

It is usual now, when a young man does not enter works as an ordinary apprentice—who is very often in these days not indentured—for him to enter as an articled pupil, paying a premium. In civil engineering, and many other professions, I think that there is no great objection to this system; but in mechanical engineering I think it a frightful mistake. No doubt there are numerous exceptions to what I shall say. There are some young men who cannot be spoiled; but, as a rule, the articled pupil has the right to loaf around as he pleases. He is not earnest in his work; he expresses small regret when he breaks valuable tools or spoils his work. He has high and mighty notions of his own importance; he cannot use his hands, but, in his own opinion, "he can out-superintend any circus manager." He is afraid of dirty work; he is altogether out of sympathy with the workmen from whom alone he can learn his trade, and in most cases he has to try to learn some other profession at the end of his apprenticeship.

And now, at last, I have come to the advice which I have to give you. You must enter a general engineering shop at once. You must find such a shop where you will be taken without premium for two or two and a half years. You will find that masters have a prejudice against young men coming from a college. We are gradually living this prejudice down. But there it is, and it must be taken into account. I have had it myself when I have been a manager or an employer, for the young man from a college is often a frightful nuisance in a shop. You must not only pay no premium, but you must get some wages, however small, from the beginning; for if you are in receipt of wages you

will at all events try to be worth your pay, and you will have a very valuable feeling of responsibility. Those of you who have most money to spare will derive most benefit in following this advice. The father of an old pupil came to me once, and almost with tears in his eyes begged me to let his son enter works, paying a premium, as the son would not do it without my consent, and I refused.

Here, then, on your leaving the College you have something to do which will test your fitness to become engineers. Talk with any experienced man on this subject, and he will tell you that it is impossible for you to obtain the sort of work I speak of; and now I say that an engineer is a man who often attempts to do what other people say is impossible. You must interview masters and managers and foremen—you must not feel so disheartened after twenty failures but that you can go to the twenty-first shop as gaily as to the first. I say to you that it is quite possible for you to obtain just such work as I have described, and it is of the utmost importance to you that you should obtain it. Some old Finsbury students have tried shops all the way from London to Leith before succeeding. Here are letters from nearly all my old Finsbury students; most of them describe their difficulties and their great appreciation of a good job when they obtained it. Here is a letter from one of our best students of last year; he stayed two months at home in the country, writing innumerable letters. I convinced him that he could never succeed in this way, and then he went off on his personal search for work, and after several disappointing days at last obtained just such a job as I have described. Any one of you who fails to succeed in this quest may rest satisfied that he has too little fortitude, courage, and patience to become a successful engineer. And you need not think that in this persistent and modest search for the only kind of work which can complete your education you are wanting in manliness. We do not think a member of Parliament wanting in manliness when he canvasses a constituency. Almost every old Finsbury student has succeeded in this quest which so many people have told them is an absurd one. [Here Professor Perry read extracts from numerous letters from old students, describing their work. Some of them are preparing for Whitworth scholarships or engineering degrees in the Royal

University of Ireland. All of them were enthusiastic as to the result of their following the above instructions.] It is not good to get work too easily, as you will not appreciate correctly such a job as I have spoken of unless it is the result of a number of personal applications.

And now as to your behaviour in the shops. Remember that your aim is to learn all that workmen can teach you. There must be no shirking of hard work, or rough work, or dirty work, no fear of working overtime should it be necessary ; you must welcome a sudden call for unusual exertion as a new and valuable experience. Remember, too, that you must learn from the men ; who else is there to teach you the trade ? Now some of these men are ignorant of theory, many of them are prejudiced in curious ways, but don't fall into the common mistake that because a workman has not read much, and knows but little of thermodynamics, that therefore he is an ignorant man. I knew a man who could barely read or write who was one of the cleverest engineers I ever knew. No one so valuable as he in a breakdown of an engine. He could take indicator cards and set almost any kind of valve motion with an instinctive perception of what it was just right to do, which always excited my admiration. If you treat workmen sympathetically you will find that, as a rule, they are very good men, good citizens, trying their best to make the world better, and helping each other to quite an extraordinary extent. But if you go among them as if you were china and they were crockery ; if you put on "side" and swagger about your poor, pitiful, theoretical knowledge ; if you let them see that you come of better blood ; if you scorn them because your families are well-to-do in the world ; if, in fact, you do not let it be seen in all your actions that you regard them as men and superiors—for be sure they are your superiors until you acquire their skill and knowledge—then you may bid goodbye to all idea of help from them, and you may bid goodbye to the idea that you will ever be able to lead men, either as a foreman or manager of works. If you want to see all their evil qualities, treat them as inferiors ; if you want to see all their good qualities, treat them as sympathetically as if they were really of your own flesh and blood. Of course there are black sheep among them, as there are some black sheep among yourselves, but remember

that not one of them is as black as you will think him to be. The advice I am giving you I never needed myself. I never yet came in contact with a decently skilful workman without feeling his superiority to myself; and I seldom meet any man who does not impress me in some direction with his superiority to myself, and I have never regretted letting such a man know, in some unobtrusive way, what I thought of him.

As for study, keep up your reading if possible. It is so very difficult to read after a hard day's work—I used often to go to sleep over my books—that I regard men who go to evening classes as quite exceptional men. But keep up your reading as much as possible. As to the cultivation of your imaginations, I am sorry to think that young men of twenty years ago were in a better position than you. They had read novels and poetry, they danced, and were fond of music. It is rather useless to give advice to you on this head.

There is one very important matter on which I wish to touch, and then I shall have done. Some of you intend, I think, to try for scholarships at certain more advanced engineering colleges, so as to proceed with your college studies for another three years. Now I want you to understand that I appreciate at their proper high value the temptations offered you—to obtain scholarships, to get an advanced, thorough, mathematical training; to work in Professor ——'s laboratory, and listen to his teaching. To men like you and me these are very great temptations; but let me tell you that these temptations ought not to be yielded to. Your ages are now on an average seventeen years. If you enter the shops now you can become good workmen; but if you enter shops at the end of another three years—and without entering shops how is it possible to become mechanical engineers?—you will not be able to learn, it will be too late to make boys of yourselves at the ages of twenty, or twenty-one, or twenty-two years. Having had a most perfect theoretical training, to put yourselves meekly and modestly under the orders of a workman; to accept his statements without a little sneering or verbal protest; at an age when you will be thinking of love-making and dressing like a "masher"; to roughen your hands in doing coarse, dirty work; the thing is impossible! Why

even I, at the age of fifteen, with nobody to advise me, found that I could not become a good workman for this sort of reason, because I had a pitiful little knowledge of mathematics, and chemistry, and physics, and held myself above my work, and greatly have I regretted it since. No; I advise you to go at once to works, and at the end of two or three years get one good session's teaching from Professor ——. Think of going to his magnificent laboratory with your present equipment, and in addition a real knowledge of actual work. You will learn more in one session after your training in the works than you can learn now in three, and you will have learnt besides to be a thoroughly good workman, at the only time of your life when such a thing is possible.

ORDER OF THE DAY (February 4, 1889)

TECHNICAL INDUSTRIAL EDUCATION BILL, 1889

Excerpt from the "Journal of the Kensington Parliament"

(*Second Reading.*)

MR. JOHN PERRY (Vice-President of the Council) in proposing the second reading of the Industrial Education Bill, remarked that no Bill following the lines of the one before them had yet been introduced into the Imperial Parliament of this country or any other Parliament, and he thought it was very fitting that it should be introduced at first rather into the Kensington Parliament, (Hear, hear.) Its provisions were rather such that nothing would be gained by a heated discussion, and they did not appeal in any way to party politics. (Hear, hear.) The object and aims of the Bill were of a non-party character, and its provisions, he might say, were in danger of attack equally from both sides of the House. (Laughter.) He would like to warn members not to rush, after reading the Bill, to hasty conclusions about its provisions. The greatest House of Commons authority on that subject a week ago assured him in a letter that the measure did not belong to the region of practical politics—that it was in the skies. It would not be fair to say very much about what occurred in private conversation, but he might state that after an hour and a half's conversation with that great authority, he had now arrived at a different conclusion, and believed that the principles of that measure were within the range of practical politics, and, indeed, he had promised help to a greater extent than one dare mention publicly. (Applause.) He was proud that such an important measure should be brought forward in the Kensington Parliament, which, as

they all knew, was the recruiting ground of the House of Commons, and of the London County Council. (Hear, hear, and laughter.) The very nature of the subject rendered it impossible to be otherwise than dull in dealing with it, but all would admit its immense importance. (Hear, hear.) A very great lawyer, Sir John Ellesmere—who, as a former Attorney-General, was probably better known to literary members of the House than members of the bar—had declared that there was a crime greater than any on the Statute-Book—that of being dull; and he was very much afraid that in speaking on such a subject as technical education even Sir John Ellesmere would have committed that crime had his audience been unsympathetic. (No, no.) A very great difficulty with which he had to contend was that the subject of technical education was not well understood, and unless one understands a subject how can one be sympathetic? (Hear, hear.) In the second clause of the Bill, amongst other things was the definition :—"Technical Education is an education in the scientific and artistic principles which govern the ordinary operations in any industry." It would be observed that technical education was not an education in pure science or in art, neither was it the teaching of a handicraft. It was that without which a master was an unskilled master, a foreman an unskilled foreman, a workman an unskilled workman, and a clerk or farmer was an unskilled clerk or farmer. The cry for technical education was simply an attack on the existence of unskilled labour of all kinds in the country—(hear, hear)—and, unfortunately, in times of bad trade, everybody took up the cry and got more or less into a state of panic, and the result of that was most unsatisfactory. (Hear, hear.) He had heard the Principal of a Provincial Technical College say that he abhorred technical education, and he had dined with eleven governors of a technical college, ten of whom did not believe in technical education. That was the result of the panic system. (Hear, hear.) Those governors and that principal were ignorant at the beginning when they conceived the idea of having a technical college; they were ignorant administrators, and ignorant critics of their own bad work when they were talking to him about it. (Hear, hear.) Nevertheless, it had been proved in evidence before a Royal Commission, and in many papers which had been

published on the subject, that unless England did go in for a good system of technical education, the trade and prosperity of the country would gradually leave her. (Hear, hear.) He might assume that they were all with him so far. (Hear, hear.) There were some who went with them a certain length, men who wrote and talked about this subject on every possible opportunity, and because of their point of view he might call them academic friends. Those academic friends were great friends of technical education, and would tell them about a German Polytechnic established in some provincial town, and that town paying £500,000 for that purpose, but, although they seemed to think that the establishment of such Polytechnics over this country would be a wise and excellent thing, they did not seem prepared to support their measure. He went further than these gentlemen, for he thought that not only ought every master of works in this country to have a good scientific education, he ought to have an education in the application of scientific principles to the particular trade he had to deal with. Clause 8 contained a provision which he thought would satisfy their academic friends, and one could easily imagine it expanded very considerably. It provided for the establishment of technical schools for such purposes as he had spoken of. By that means they would have, in the language of Professor Huxley, a sort of large net by which they might catch embryo Faradays if they happened to crop up —(hear, hear)—and give them a chance of development. If in every twenty years they caught by that means one young Faraday, it would be worth all their trouble. (Hear, hear.) Their academic friends did not go far enough. They always spoke about the education of the masters and of the managers, but that was certainly not all that was required. (Hear, hear.) During all the agitation in favour of technical education, there had been going on a sort of inarticulate cry from the workmen, and the Government had endeavoured to the best of their ability in framing that measure to translate that inarticulate cry. The workmen seemed to say, "We hate machinery, but we know it is an unreasoning hate. We know that Queen Elizabeth did not possess many of the luxuries which ordinary women possess nowadays: where there was then one hand-loom weaver, in the days of Silas Marner, we have now hundreds employed in

the weaving industry ; but still we hate machinery because we see so clearly some of the evil things it does. We believe that bad trade means bad methods of managing business and old-fashioned machinery. We also know that at the present day we have for one skilled workman twenty unskilled workmen in our factories, and that a youth by turning two or three handles of a labour-saving tool could in a few minutes turn out a finished piece of work, which, thirty years ago, or before the tool was invented, would have taken several weeks. Now, all that, from one point of view, was splendid ; but what they had to think of was, what would happen when that youth grew up ? (Hear, hear.) Machinery maintained in this country a very large population, but of what use is all this if every unit of the working-class population is an unskilled workman ?" (Hear, hear.) The workmen were also beginning to say that machines were becoming more and more self-acting, and that their labour was becoming more and more of a purely unskilled kind ; in other words, that the machines were becoming the lords of creation, and men were becoming menials. Of course, it was clear to everybody that there was an immense number of unskilled workmen ; but it was not sufficiently recognised that the masters were also, to a very great extent, unskilled. Many of the masters and owners of works had received from their fathers a good business, but they did not possess the skill to mould and change their business to meet the requirements of changed circumstances, as their fathers or grandfathers would have done. These old men were skilled labourers. He had gone into the matter very fully with those who seemed to think that technical education was really only required for masters and managers, and their position was logically this, and they admitted it ; in their view what was wanted for the purpose of turning out really good work was an exceedingly skilful manager and foremen, good machinery, and an army of slaves. A mechanical engineer of eminence, who is also an authority on technical education, had said, "What we want is a manager who has had a thoroughly good technical education, obtained solely at a technical college, good labour-saving machinery, and then—not an army of English workmen, who grumble and complain—but 500, or 600, or 1,000 negroes, and then we can turn out excellent engineering work." He had not

time to enter into that fully. It was a very strong, it was an ably supported statement; but there were several very serious objections to it. Such ignorant workmen made very bad material as the citizens of a great country like this. (Hear, hear.) Apart from that consideration altogether he was convinced that it was bad for trade, and bad for the master, to have workmen in that sort of condition—mere human automata, without imagination, without initiation, without individuality, mere labour-saving human tools. What would happen to such men when some change took place in the mode of manufacture? Why, they would be thrown out as "scrap," and would not be able to turn their hands to any other kind of employment, for after years of such labour their intelligence would be like the snakes of Iceland, non-existent. So that, as they would not be so certain of constant employment, he should think their wages would have to be rather raised than lowered in the long run. And now for the most important objection to the "army of slaves" theory. It was assumed by those who wished to confine technical education to the masters and foremen, that the masters were the sole inventors. No doubt most patents were taken out by them, and he admitted that they were justly entitled to them, and were not wronging any one; but he affirmed, as an inventor who had brought out many patents, that the inventions chiefly came from below. It was the man who actually worked with the tools who gave the hints which led to inventions. (Hear, hear.) The master or manager in going round the workshop found an idea here and another there—or the millionth of an idea, it might be, and thus many useful inventions were made. (Hear, hear.) Surely it must be admitted that inventions came from the continual interchange of ideas going on between masters, foremen, draughtsmen, and the workmen, and from workmen continually rising to be foremen and managers. Now, if you had unskilled, unimaginative slaves as your workmen, how was it possible to have invention? (Applause.) It was said by some, give the workman—not a technical education, but a good general education, and then he would not be the mere machine he so often is; give him a School Board education, and that would be sufficient. But was that enough to make a workman intelligent? (No.) How were they to make a man intelligent by giving him a

School Board education and denying him a knowledge of the principles underlying the things he works amongst? Without such knowledge he would be slaving away all day long without interest in his work, and even scorning it the more on account of the general education he might have received. He is engaged in making a little bit of a steam-engine, but he has not been told anything about the properties of steam, or how one part is connected with the other part, or about the history of the steam-engine. Surely that kind of instruction would make him take an interest in his work, and with it he must be a much better workman. He wished he had more time to devote to his answer to his engineering friend's "army of negroes" theory; but it would be observed that he fought him on his own ground.

Clause 3 of the Bill provided that a boy or girl before leaving school should get some information about science and art. A knowledge of physical science, or some particular branch of it, was of very great importance to a boy, and fitted him to become a superior workman; not only because it made him more intelligent, but because the training he received in a physical laboratory was an excellent training to the hand and eye (Hear, hear.) If by children remaining longer at school they could be fitted to become better workmen, and thus secure better wages, parents would not be so ready to take them away at too early an age, and this would especially be the case when masters showed a preference for such children as apprentices. The idea of having workshops in schools was good in some respects, but there were many objections to it. In the first place, scientific education in laboratories would be very much better. (Hear, hear.) Next, speaking from the point of view of a practical man, he urged that if they wished to make a boy a good cabinet-maker, or joiner, or anything of that kind requiring handicraft skill, then he ought not to touch a tool until he is about the age of fourteen, except for amusement. When he was a master at Clifton College, he established the first workshop in connection with a public school in this country, a workshop which was a great success from the very beginning, and he could speak from experience. (Hear, hear.) It was a very good thing as an amusement, especially on wet days, when such work might take the place of cricket or football, but

in a primary school there was a danger of letting it trench upon the regular school work. Again, as a training for the hand and eye, such games as top-spinning, marbles, football, fives, and so on, gave training which was even better than the training obtained in school workshops.

Clauses 4 and 5 were really the most important clauses of the Bill, as they dealt with the question of apprentices. Under the old system, the master used to have one, or at most two, apprentices, who lived in his house under his care. The apprentice was taught his trade in all its branches by his master, he lived with the family, his moral and religious education was not neglected, and in very many cases he married his master's daughter, and succeeded to his master's business. Strange to say, that system still survived, to some extent in Sheffield, to this day; not, of course, with the employer who had 500 or 600 workmen, but with some of the workmen who had their own apprentices, and the masters acknowledge their right to bring those apprentices into the works. That was a remnant of the old system, which he would like to see further encouraged and developed. That was the *beau ideal* of apprenticeship. Now the London solicitors' idea of all apprenticeship was that the apprentice in any part of this country did always pay a premium. (Laughter.) The document he held in his hand was the usual form of apprenticeship indenture all over the country, and the boy began with three shillings a week for the first year, and went on for seven years, ending with nine shillings a week. When the boy gets to the end of the seven years, one week he gets nine shillings in the shape of wages, and the next week he gets thirty shillings or thirty-four shillings, and in many cases he is in a position to get married. (Laughter.) That seemed to show that for years he had been working for less wages than he was worth. (Hear, hear, and No, no.) He would assert from his own practical experience, that from the first year of a boy's apprenticeship, he was usually worth more to the master than the wages he received. (Hear, hear.) Now, how did the master perform his part of the contract?—because there were two sides to the contract, and the master's part was to teach the boy his trade. In the olden days he did it; but now he simply sent him into the workshop, and took no further

trouble with him. It was a very fortunate thing that in this country the workmen willingly taught those boys, and gave them all the information they could, which they were not bound to do. They had a right to insist on the masters performing their part of the contract, and therefore the fourth clause provided for that. He believed masters were for the most part willing to do their duty in that respect, and he would mention the firm of Messrs. Mather and Platt, who had already established schools in their works for their apprentices. The technical education of the apprentices and the workmen would benefit them—would benefit the industry to which they belonged, benefit the masters and the people of the country generally. All were therefore interested in furthering the education of the workmen in the principles which underlie their trade.

The fifth clause referred to the way in which the education should be given. What means were there at present for educating apprentices and workmen? The Government departments sometimes neglected their duty, but, in spite of some faults, the science and art department had done exceedingly good work. (Hear, hear.) Then there was education given, or supposed to be given, by what were called Polytechnics, but which had nothing in common with the German Polytechnic. The latter was a scientific university, but the Polytechnics in this country had almost nothing to do either with pure scientific or with technical education. They provided swimming—(laughter)—and gymnastics, and coffee-rooms, and things of that kind, and their proper name was the name used by Mr. Besant, "A Palace of Delight." They were very excellent things in their way, and had his sympathy; but it was well to point out that they had nothing in common with technical education.[1] Then, with regard to evening classes, it must be remembered that less than 10 per cent of the workmen and apprentices in this country could possibly attend them. No good could be got from evening classes unless men attended with great regularity at least four nights a week, and even then the teaching could not be very systematic. The men who went to those classes were, in many cases, men who sacrificed their wives and families, and their

[1] The London Polytechnics are now (1900) places where most excellent scientific and technical instruction is given.

duties as citizens to a great extent, and might themselves be called heroes and martyrs. He knew of a man getting home night after night at twelve o'clock, who had to rise next morning at four or five o'clock! Of course, such a man deserved to succeed, and he would succeed, too, if he did not die; but the chances were he would die. (Laughter.) It was quite evident they could not expect all apprentices to do that sort of thing, to sacrifice their social duties with regard to courtship and marriage, citizenship and politics. (Hear, hear.) Let any member present work at a bench from seven to six; let him eat in the evening the dinner he has earned with the normal workman's appetite, and then see how long he can keep from sleeping when attending an evening class, and see whether it is possible for him to get to his evening class at all in the pleasant evenings of May and June, when it is so much more natural to loaf around in the open air. The Bill before the House would improve the existing evening classes and develop them, but that was not enough. (Hear, hear.) They had no right to expect the apprentices to educate themselves at those classes. Their education in the principles underlying their trade they ought to learn to some extent in the master's time, and in the workshop, if possible. It would be noticed that the system of education would be left largely in the hands of local authorities, and that disposed of an enormous objection which had been offered to many schemes of technical education; namely, that the examinations are too much centralised. There were many things, especially about trade matters, about which an examination paper could not be set, and it was therefore far better to leave them to the care of the people of the district. (Hear, hear.) Also the hours of study were better left in the hands of the local bodies, than in the hands of a central body in London. The Bill did not prevent the local authority from establishing science and art classes, and would conduce to a better attendance at the existing science and art classes. He was afraid that he had failed to convey the impressions he wished to convey. (No, no.) He hoped that the thin sketch he had given them of a very magnificent subject, would, at all events, have given them a glimpse of the importance of this great subject of technical education. (Applause.)

A BILL FOR TECHNICAL INDUSTRIAL EDUCATION

Prepared and brought in by the Vice-President of the Council, the Prime Minister, and the Attorney-General

WHEREAS, it is expedient to make provision for Technical Industrial Education in England and Wales:

Be it therefore enacted, etc.

1. This Bill may be cited as the Technical Education Bill, 1889, and shall not extend to Scotland or Ireland.

2. "Apprentice" means any boy of less than 18, or any girl of less than 17 years of age, employed, whether under Indentures or not, in any place which, under the Factories or Workshops' Acts, is denominated a Factory or Workshop, for wages, or other remuneration. "Master" means the employer of any apprentice as hereinbefore defined.

"School Authority" means the School Board exercising jurisdiction in the District in which the place of employment is situated, or any elected body which may take over the powers of such School Board; and in places where there is no School Board, it means the County or Borough Council under the Local Government Act, 1888, or the Municipal Corporations' Acts.

"Technical Education" is an education in the Scientific and Artistic principles which govern the ordinary operations in any industry.

"Technical School" means a place for Technical Education, whether established and maintained

A. By the School Authority, and open to all Apprentices;

B. By voluntary effort, and open to the Apprentices of more than one Master:

C. Or by a Master for his own Apprentices.

"Inspector" means the Inspector of Factories in whose District the place of employment is situated, or if there be no such Inspector, then the School Board Visitor for such District.

3. The Education Department shall forthwith and from time to time prescribe regulations in conformity with the rules for the time being of the Science and Art Department in the subjects in respect of which Parliamentary Grants are made by the Science and Art Department, for the formation and instruction of classes of elementary school children who have passed the Fourth Standard, and thereupon the School Authority may form such Science and Art classes, and provide such instruction accordingly, and earn such grants, and may assign such grants to the Teachers of such classes, or may otherwise provide for their remuneration.

4. Every Master shall provide each of his Apprentices with Technical Education at a Technical School.

5. Every Apprentice shall devote at least one hour a day, five days in the week, during working hours, to study at a Technical School.

6. The School Authority shall annually in January prescribe the time for such study, having regard to the usual working hours in places of employment in their District, and shall publish a Table of the times so prescribed. A printed copy of such Table shall be conspicuously exhibited by the Master in every such place of employment in such positions for such times and in such type and form as the School Authority shall prescribe.

7. The School Authority shall have power to establish and maintain such Technical Schools as may be necessary to accommodate and provide Technical Education for all Apprentices in their District whose Masters do not otherwise efficiently provide for the Technical Education of their Apprentices. The Master of each Apprentice shall pay the prescribed fees for his tuition at such Schools, but not exceeding £1 per annum for each Apprentice.

8. The Technical Schools established and maintained by the School Authority may provide Technical Education for persons other than Apprentices.

9. The course of studies at such Schools, and fees payable for the same, shall be prescribed from time to time

by the School Authority, subject to the sanction of the Education Department.

10. The Inspector shall inform himself as to the sufficiency of the Technical Education given to Apprentices in his District, and report thereon to the School Authority and the Education Department at such times and in such manner as they shall respectively prescribe.

The duties, powers, and penalties relating to the office of Inspector specified in the Factory and Workshops' Act, 1878, shall be applicable to any Inspector under this Act, and to any place of employment within the provisions hereof.

The Inspectors shall be paid by the School Authority such remuneration for their services under this Act as the Education Department shall approve.

11. All offences under this Act shall be prosecuted, and all fines under this Act shall be recovered on summary conviction before a Court of Summary Jurisdiction in manner provided by the Summary Jurisdiction Acts.

The provisions of the Factory and Workshops' Act, 1878, and the Acts amending the same as to legal proceedings and appeals, shall be deemed to be incorporated in, and made applicable to, this Act.

The punishment for any offence under this Act shall be a fine not exceeding £5.

12. The expenses of carrying this Act into execution shall be defrayed by the School Authority, who shall have power to provide for such expenditure by moneys raised, precepts issued, or rates levied under their powers. Separate Statements of such expenditure shall be furnished annually to the Education Department.

TECHNICAL EDUCATION

LETTER TO "THE ELECTRICIAN," DECEMBER 22, 1879

THE old system of apprenticeship in England obliged the master to teach a trade in return for a certain term of service. In consequence of the nature of trade having changed, it is now impossible for the master to carry out, personally, his part of the contract, and any one who has been in an English workshop must know that, what with the ignorance of masters as to what goes on in their works, what with the duty of a foreman having become that of a taskmaster, what with the old idea having died out of a master's duties to his servants possessing no money equivalent, an apprentice gathers a poor knowledge of his trade with the greatest difficulty, even when he is not hampered by a want of elementary education in Physical Science. The workmen with whom he comes in contact regard their engagements from a mere pecuniary point of view ; they will leave a workshop to-day and enter another to-morrow. In fact, even if they had powers of teaching the apprentices, they have no interest in so doing ; or rather, they have an interest in keeping back as a trade-secret any information which can give them, as its possessors, a temporary importance.

It is high time that a change should be brought about in the apprenticeship system of England. The ignorance of workmen is a canker at the root of all the trade supremacy of the country, and it is our duty to see that it is cleared away.

The objection to the establishment of State-paid trade schools seems to be insuperable, in this, that it is wrong to benefit particular trades at the expense of the whole people of the country, and, however much we may extend the

operation of any trade-school system, it can never be equally beneficial to all people. By compelling masters, whose fortunes have been created by, and are dependent on particular trades, to take cognisance of the facts—that they have duties to perform in regard to their apprentices; that they have hitherto been in the habit of entering into contracts without having any means of performing their parts of them, and that it is better in every way to see a higher duty towards not only their apprentices but their workmen than is to be cleared off by a weekly payment of money—by doing this we shall not only improve trades, but we shall bring back again those old feelings of loyalty of men in different positions to one another, whose absence is the social difficulty of modern England.

It is generally recognised to be the duty of the State to insist that all children shall get a fairly good elementary education. In a short time, when the great primary expenses, such as that of building, have been cleared off, there can be no doubt that the education insisted upon all over England will include a little Mathematics, Physics, and Chemistry. That it is possible for all children such as now attend the primary schools of England to benefit by teaching of this kind, is well known to everybody who has studied the work of the Irish National Education Commissioners, and must be evident to anybody who cares to visit a large national school in Ireland, such as the Model School at Belfast. To provide the children of the country with education in Natural Science is recognised as a duty of the State by the payment of money every year to teachers of science and art classes; and in these two ways, that is, by giving very elementary instruction in primary day schools, and more advanced instruction in evening classes, do I think that the State will be performing a duty which comes in a legitimate way within its sphere. For a long time to come it will be difficult to obtain such instruction as every one who has examined the working of Science and Art evening classes knows very well; but the improvement which takes place year by year in such teaching, shows that the time must come when everybody in England will obtain a sound elementary knowledge of Natural Science at a cheap rate. To provide this general instruction is the duty of the State:—(1) because it is equally beneficial to us all

that the children shall be educated in elementary Natural Science, (2) because experience shows that a general scheme is necessary for effecting the purpose; and (3) any such general scheme is so large that it can only be taken up by the State. But here I think that the functions of the State must end. Education in science applied to particular trades must be the care of the people who most immediately benefit by those trades.

Having come to the conclusion that apprentices must be taught their trades in a more efficient manner than the one generally adopted in England, and also that the apprentices who are to be taught in the future will possess a sound elementary knowledge of Natural Science obtained through the agency of primary schools and evening classes, how is this instruction in their trade to be given them? If we consider the great number of apprentices who are to receive instruction, we must, in spite of the well-known experiments on the Continent, come to the conclusion that the practical part can only be given to them in ordinary workshops.

The experience of all people connected with industrial schools and workshops attached to prisons is that the work turned out, even when it can compete with outside work, is done at a great pecuniary loss. Workships established generally throughout the country for the education of apprentices would labour under the same and other difficulties. 1. They would require a fair proportion of workmen to the number of apprentices and would consequently form important and possibly unnecessary additions to the manufacturing power of the district in which they were established. 2. It would be difficult to prevent the workmen being intimidated by trades unions and the jealousy of manufacturers. 3. Although established as schools it would be necessary to make for them a connection of customers, and as there is so much competition in trade a large staff of travellers, agents, and clerks would have to be kept up. The cost of advertisements, the necessity of changing machinery as soon as it became antiquated in form, the necessity for having a good business man as manager, who would keep himself well acquainted with the state of trade, these expenses would be the same in the school as in a manufactory. 4. The special requirements of a school would be additional expenses of such magnitude

that there must always be great pecuniary loss in competing with other manufactories.

It has yet to be proved that any success attends the establishment of such trade schools as we are now speaking of in France and Germany ; and even if these were successful, since they have rather been established for the creation of trades in districts where such workshops had hitherto no existence, than for the very different objects of which we are now speaking and under such different circumstances, I contend that they can never prove a success in England.

A trade can only be properly learnt in a real workshop where there are many men as well as apprentices. This statement has not been disproved by any of the Continental experiments which have hitherto been made, and it is a statement which will be made by all men practically acquainted with workshops, in spite of the fact that boys in a school workshop will construct things useful to themselves or in their own households. I established what is, I believe, almost the oldest workshop existing in any public school, when I was a master at Clifton College, and found it a complete success in every way ; but although we provided a competent foreman, and the boys had two or three hours a day to devote to their work, their manual dexterity at the end of three years was far inferior to that of the youngest apprentice in a real workshop at the end of one year. Objection may be taken to arguments founded on such particular experiments as this, but there is always the fact that great manual dexterity has never yet been acquired by any man whose experience has not begun and ended in a real workshop where there were more men than apprentices.

The object in view in establishing workshops in connection with science classes has always been that of giving students an intimate acquaintance with the properties of materials, and I consider that no classes in Natural Philosophy can be carried on efficiently unless the students use the saw and plane, the hammer and chisel, the forge and the lathe. But this is very different from instruction in the trades of the carpenter, fitter, blacksmith, or turner. In learning their trades, apprentices must mix much with workmen, work near them and on the same jobs, and lay themselves out to help and please the men whose manual dexterity they

admire. But it is no less true that they must be taught the general principles of their trade in an efficient manner.

The general principles of a trade, or what may be called the application of the principles of Natural Science to a trade, cannot be learnt from workmen, and can only be learnt by attending lectures and lessons specially adapted to the trade; and it is in the establishment of such technical classes in the neighbourhood of workshops that I look for improvement in English manufactures. Thus, although we do not want to change our system of letting apprentices learn much of their trade from ordinary workmen, we might cause masters to see that their apprentice not only attends the schools of the district where Natural Science is taught but also that he gets time and the opportunity of attending classes where the application of physics or chemistry to his particular trade is taught.

It is sometimes used as an objection to the scientific education of workmen that boys who attend science classes do not find any great ease in learning their trade. This I grant as a fact, and if we consider how vaguely a pupil at science classes of the common kind gets acquainted with scientific principles, how far removed these principles are from being directly applicable in a man's trade, how well he knows that existing workmen get along without a knowledge of scientific principles, and if we consider the hundred other influences which cause him to doubt the usefulness of his scientific education, we shall discover the reason why attendance at science classes has hitherto seemed to be followed by no useful results. There is a very great difference in the positions of an apprentice who has learnt a little theoretical mechanics, and physics, and chemistry, and who has nobody to show him the application of his knowledge, and another apprentice who has been taught the application of scientific principles to his trade. I have myself experienced the miserable feeling of the first, when a boy. I was a fairly good mathematician, and was fond of natural science, but in every direction I found that it was impossible to apply my knowledge in mechanical engineering. I am sorry to think how much time was wasted and misery experienced before I was able to apply my scientific knowledge to the operations going on in the workshops. I have, however, lectured to boys already acquainted with Natural

Philosophy on the application of their knowledge in mechanical engineering, at one of the greatest of technical colleges, the Imperial College of Engineering in Japan, and I have observed how rapidly these boys acquired dexterity and knowledge of their trades in large workshops during their vacations from college; and this is the experience of my colleagues in the Telegraph, Mining, Building, and Chemical departments of the college. It is the experience of all professors in technical colleges that their students are capable of picking up a good knowledge of a trade in half the usual time, although placed among workmen in the same way as ordinary apprentices.

For the great body of English apprentices what I advocate is the establishment of classes in the neighbourhood of workshops, where, during two hours a day, they may learn how a knowledge of Natural Science is applied in their particular trades. These classes ought to be day-classes, because, as it is the duty of masters to educate their apprentices, and as we cannot give apprentices less leisure time than workmen have, and as their pay is always very small in comparison with that of men, the time necessary for instruction in their trade ought to come out of the regular working hours.

There is a part of the education of an apprentice which cannot easily be looked after by any organisation, and this because there are really trades in which secrets are of importance—I mean his experience in the workshop itself. If it were possible to have an instructor who would devote his time to the instruction of a certain number of apprentices in a district, who might be admitted to the workshops to spend, say, a quarter of an hour or more with each apprentice per week, a man not only acquainted with the trade but with Natural Science, I should think the scheme complete. Possibly, in particular trades, an organisation of masters might enable this idea of instructors to be carried out, for the expense would be inconsiderable per boy, and, in many important trades, there is no great objection to a stranger's coming into the workshop. Indeed, in most cases, the only objection would be one of expense, as there might be a sufficient number of apprentices under one firm to take up the whole time of such an instructor.

Even without these instructors, however, our scheme of

education would be pretty complete. At all events, such instruction as I wish to see given in the technical classes would enable apprentices to learn their trades with a thoroughness not obtainable in any way at the present time.

The initiatory step in carrying out such a scheme will involve the outlay of a large amount of money, and the City Guilds of London seem to be, just now, the only organisation of trades in a position to undertake it. They have already taken over the examinations of the Society of Arts in the application of science to particular trades, but it seems to me that they ought previously to have insured instruction. In the present case, I think that it is useless to follow the example of the Science and Art Department, for previous to 1860 the country contained numbers of men who had a notion of what the teaching of natural science consisted in, but at the present time, how few there are who have thought of the teaching of applied science. The first step to be taken by the City Guilds is, to show the country how far it is possible to teach the application of science to particular trades. By the help of engineering colleges, the Royal School of Naval Architecture, the School of Mines, the Yorkshire College of Science, &c., it has already been shown that some such teaching is possible. But the new scheme must comprehend the teaching of the application of science not only to mechanical engineering, mining, weaving, and dyeing, but to all the great trades of England. If we consider what difficulties will surround such a scheme from the beginning, in finding men capable of instructing themselves first and then adopting the best means of instructing others, the cost of experiments which fail perhaps several times to give the results expected, and the expense of buildings and apparatus, we shall get a small idea of the magnitude of the undertaking and how useless it is to think of any other organisation than that of the City Guilds taking it up.

Technical colleges, established in London, would have functions which it may be a little difficult to define at the beginning, but it is evident that they would occupy the position of universities to which all the technical classes of the country would look for guidance and examination. One kind of college which might be established in a

manufacturing neighbourhood would have night classes for apprentices who could pass a certain examination in Natural Science, give them further instruction in certain parts of mathematics and natural science and perhaps modern languages, and afterwards thorough instruction on the application of science to their particular trades. Such a college might be utilised in the day time in training boys from primary and other schools in pure and applied science and the use of tools; and arrangements might be made for getting these boys entered as apprentices at workshops at later ages than other apprentices and for shorter periods of service. Apprenticeship and education finished, either class of students might become foremen of workshops or teachers in technical schools throughout the country.

Another kind of college that should be established in London, not necessarily in a manufacturing neighbourhood, would provide for other trades just that kind of instruction which the School of Mines provides for mining—that is, no connection would be maintained with manufactories, its students would devote no part of their day to workshops, although, perhaps, certain parts of the year might be set apart for either visiting many works or for working in particular places. Such a college as this might well become the heart of the whole system, with the best paid professors and buildings and apparatus, and with the general office, sending out men trained to become professors at the other colleges or to become managers of works.

We have no great difficulty in understanding how this central college would work, for we have the School of Mines before our eyes, and its system of high fees for rich students and scholarships for poor students is well worthy of imitation. It is the secondary colleges for manufacturing districts which will give most trouble as costly experiments. Nevertheless, I think that a secondary college, although costing, perhaps, only fifteen or twenty thousand pounds to establish, will have as important a function to perform in the education of the manufacturers of the country as the central college of five times the cost. In fact, the establishment of the central college is a comparatively simple matter. The four or five great technical colleges of the world will be useful for purposes of imitation and improvement. But where can we find an example of such institutions as are

required in our secondary colleges — colleges specially adapted to the peculiar needs of England ?

When I read the inaugural address at Cowper Street of my late colleague, Professor Ayrton, I hoped that a great attempt was about to be made to solve the problem. But the information I have been able to gather of the Cowper Street scheme shows that as an experiment it is too small to lead to important results. Unless the Guilds are prepared to spend, say twenty thousand pounds at Cowper Street, and to appoint additional professors with energy and experience like the two they have already chosen, the initiatory step in a scheme of technical education for England must still be regarded as yet to be made. The experiment will have to be made on a larger scale before it can promise success, and I think that the condition of the country and the riches of London warrant the commencement of a much larger undertaking without further loss of time. I would not advise the City Guilds to do more than establish a central college and these secondary colleges in suitable manufacturing neighbourhoods. They have already a scheme of examination for technical classes. The rest will be the easy task of organisations of men engaged in manufacture throughout the country.

THE TEACHING OF TECHNICAL PHYSICS

PAPER READ BEFORE THE SOCIETY OF ARTS, JANUARY 22, 1880

IN the struggle for existence of men and nations, the most important factor at all times has been a knowledge of social and natural science, and to acquire and add to this knowledge, and apply it in all his actions, is the study of man from the cradle to the grave. Every man knows, perhaps unconsciously, what are the things which he may not do with impunity against the laws of nature, and what are the phenomena of nature on whose recurrence he may depend; he knows that a better knowledge of physics will give him more help from nature's resources. Most men tumble up through boyhood without special teaching in physics, but in numberless ways they obtain a practical knowledge; that is, they are so environed by the forces of nature that in every action they are learning from observation and experiment. Every man is constantly being influenced by the results of his own experience, and on performing any new action he unconsciously uses a physical theory of his own. The object of teaching physical science is to give all men the same language in which to express their experience, so that all may employ the best methods of simplifying the phenomena which they have to study, and give their results to other people.

The principles of physical science are, like any other language, most easily learnt in youth. I have known children to gain a greater colloquial knowledge of a foreign language in six months than their parents gained in as many years. What a wondrous meaning and history is contained in almost every word of every language!—yet a child learns to use the word unconsciously. No doubt such words as these, when they were first invented, were

studied over and lectured upon, just as is the parallelogram of forces now, and we may depend upon it that children of the future will take in the idea of the truth of the parallelogram of forces as easily as they now accept the simplest of Euclid's axioms. When Egyptian and Chaldean philosophers spent years in difficult calculations, which would now be thought easy by young children, doubtless they had the same notions of the depth of their knowledge that Sir Wm. Thomson might have now of his. How is it, then, that Thomson has gained his immense knowledge in the time taken by a Chaldean philosopher to acquire a simple knowledge of arithmetic? The reason is plain. Thomson, when a child, was taught in a few years more than all that was known three thousand years ago of the properties of numbers. When it is found essential to a boy's future that machinery should be given to his brain, it is given to him; he is taught to use it, and his bright memory makes the use of it a second nature to him; but it is not till after-life that he makes a close investigation of what there actually is in his brain, which has enabled him to do so much. It is taken in because a child has much faith. In after years he will accept nothing without careful consideration. The machinery given to the brains of children is getting more and more complicated as time goes on; but there is really no reason why it should not be taken in as easily, and used as readily, as were the axioms of childish education in ancient Chaldea. A watch is a complicated piece of mechanism, which it has taken the thought of all the ages to elaborate, but the smallest boy can make it useful to himself. In a recent number of *Macmillan's Magazine* there is a paper by the late Professor Clifford on "Boundaries." It directs attention to some of the simplest mathematical ideas. I felt, when reading it, that nobody could take a greater interest in it than a mathematician who had long used those ideas. The notion of a boundary had long been simple to him, and useful, like his watch to a boy; but one day he looks into its mechanism, and, without its becoming less useful, he finds that it opens up for him a world of thought. The simplest-looking geometrical idea, the simplest statement of any general law in nature, is a result of the experience of many generations of animals and men. The student who cavils at Euclid's axioms, who

refuses to employ the idea of limits and of infinities, will probably never advance very far in mathematics; and this is one of the reasons why ladies find so much difficulty in their studies; they begin after their reasoning faculties are developed. It is interesting, from this point of view, to listen to remarks made by lady students of mathematics about their teachers. They assert that it is because mathematics has so long been the peculiar property of men, and, therefore, of coarser intelligences, that doctrines such as that of limits and infinities should be accepted without question by students. They cannot understand that they are really beginning in the middle of the subject, that to begin at the real beginning would be utterly impossible, and, in fact, that mathematics is merely an inductive science based on experience.

It follows from what has just been said, that a system of education which suits one generation may be very unfit for the next; what suits boys in schools may be unfit for grown-up women and men; and, in teaching natural philosophy, which includes mathematics, we may begin on any data that are believed by our students, if we know them to be true. It is to be remembered, however, that the great distinction between children and adults lies in this, that children are ready to believe anything, although we may have some difficulty in making them understand; whereas, adults can understand easily, although they may not believe readily.

It is easy to show that, when a system of education becomes fossilised, and when it is the interest of any body of men to oppose changes in it, it becomes degraded. Take, for instance, the teaching of Euclid in schools. It is quite possible to begin more in the middle of the subject of geometry, teaching students to test by actual experiment the truth of many of Euclid's propositions, giving them data which they know to be experimentally true, and which we know to be generally true; to give them a real interest in what they work at by commencing early the study of physics, so that their observational and reasoning faculties may be more rapidly developed than they possibly can be when we begin with abstract truths, and a series of enigmas, like extracts from the Shorter Catechism of the Presbyterian Church. Our Tom Tullivers sit brooding by

the hour over a proposition in Euclid, hardening their hearts, and dulling their understandings, and we call it mental training! Why not tell the boy that the forty-seventh proposition is always true, and let him test the truth with squares of paper and with numbers? Following Euclid, he will not understand that he has proved a proposition until years after he believes in its truth. But, if we begin to teach him physics at once, he will see that not only is he getting mental training, but every result which he gets out has its useful applications. I know that many workmen who begin Euclid with energy, give it up after a year or two in disgust, because at the end they have only arrived at results which they knew experimentally long ago. The idea that a study ought to appear to be useful to a student is ridiculed overmuch, I think. Like all wide-spread notions, it is founded on common sense, and I believe that any teacher who neglects to consider the instinctive preference of his pupils to reason about things rather than about ideas, is a man who persistently refuses the powerful aid of nature. I may also remark that, besides the waste of time, there is another consequence of training in Euclid which ought to be much deplored, namely, that men think too much of logic and too little of the matters to which the logic is applied. Euclid's axioms are so true that the consequences derived from them do not require to be tested, and hence men trained in this school are apt to believe too well in the logical consequences of any seemingly general fact, forgetting that very few general statements are absolutely true and that all logical consequences have to be tested experimentally before we can say that they are true.

I would suggest that no child of less than fourteen years be compelled to take up Euclid, and, indeed, that nobody take up this study until he has been well grounded in physics, the study of which can begin at any age, and, indeed, does now begin in infant schools under the kindergarten system; that we urge forward the introduction of a decimal system of weights and measures, and make more use of what is known as the scientific method of teaching arithmetic; that practical, plane, and solid geometry, made simpler than it is at present, be taught as an experimental subject, like mechanics and heat; and that algebra be taken

up as it enters into physics, and just so far as it is necessary for obtaining a quantitative knowledge of the phenomena of nature, but that it and a little trigonometry should precede Euclid. I have no doubt that if this system is followed it will be found easy to give to boys, before they leave the primary schools, not only a good knowledge of natural science, but also a power of observation, a thirst for information, and a method of reasoning which will serve them much better in this nineteenth century than what is to be obtained in any other way.

It will be seen that, in speaking of physics, I have been dealing altogether with quantitative experimental physics. The study of physics cannot exercise the reasoning faculties unless it is quantitative. It may exercise the wonder of a child, it may please his senses, to see certain well-known experiments, say in electricity, where, with glass-legged stools, and Leyden jars, and electric machines, the teacher may show off numberless tricks to his audience; and, possibly, for young children, there may be great instruction in such exhibitions, but they ought not to continue too long, nor ought they to be given, except as a preface to quantitative experiments.

In pointing out that, as time goes on, we must begin from more and more comprehensive data, in fact, that pupils must commence their studies farther and farther from the real beginning of the subject, I point to a fact of which every teacher of physics gets good evidence, even in the history of twenty years. Teachers of mathematics have not this evidence; but the teaching of natural science is obeying natural laws as yet, not being fettered by crystallised rules and vested interests. Instead of teaching pupils a great mass of disconnected facts, and giving them lectures on virtual velocities, and the like, as was common ten years ago, we begin with a great generalisation, the law of conservation of energy. And yet, after this generalisation was known to men of science, how long it was before teachers ventured to prune away excrescences from the text-books; how long it was before they ventured to say, "It is not necessary to teach as we ourselves were taught; we can do better; we can give in a few words, and illustrate by a few experiments, a general law which it required years for us to understand." Changes occur slowly; books are still written

as they used to be written years ago; and it takes long for our older professors and teachers to recognise the need for modern text-books like Thomson and Tait's "Elements of Natural Philosophy," or the valuable little book of Dr. Lodge. Any person who takes up Everett's "Natural Philosophy," or Fleeming Jenkin's "Electricity," or any of the more modern text-books, will see that in physics we are really beginning at more and more advanced points of the study of physics. Instead of finding in these books a mere record of old experiments, described just as they were originally performed and described by their discoverers, we find that fewer experiments are given, and what are given lead the reader naturally to the generalised principles under which all such phenomena may be grouped. Of course the student knows that to test completely any such principle would take a lifetime, but he has faith in what other men have done, and it is sufficient to give him just so much experimental illustration of a principle as he can grasp and can use. Nothing has so much conduced to this generalisation as actual measurements of phenomena and the use of mathematics. Hundreds of seemingly disconnected phenomena are shown to be included under one principle, when we study them quantitatively.

In teaching physics at a public school in 1870–3, I was greatly helped by possessing a workshop, where most of the boys were able to make apparatus with which they could, themselves, repeat all the experiments shown to them in lectures; and even with the limited supply of apparatus in my possession, I was enabled to let every boy manipulate for himself the proofs of most well-known physical principles. I consider that nothing is more important in a school than this, the actual handling and constructing of simple apparatus by the boys themselves. Beyond this it is almost impossible to go in a school laboratory, except with one or two pupils who may really prefer helping in weary observations to cricket or football. I remember that two such pupils had the patience to take up of themselves the repetition of most of the experiments recorded in a very long scientific paper by an eminent physicist; but, indeed, the duties of both master and boys at a public school are too heavy to allow much of this kind of work, or of original

work, to go on. I wish I had time at my command to apply the theory, that methods of education which suit one generation ought to be altered for the next, not merely to that minor part of the study at any public school, mathematics and natural philosophy, but to all the studies there, and to comment upon the questionable wisdom shown in the most advanced schools, of shunting to these subjects such boys as do not show ability in ancient classics.

If the changes in teaching mathematics which are suggested above take place in primary schools, I see no reason why the principles of physics should not be intimately known to every child who has passed the age of twelve years; that is, if the lectures given to the children be illustrated by simple apparatus, such as the Science and Art Department helps to supply, if the teacher is himself acquainted with quantitative experimental physics, and if the children are encouraged to make simple apparatus for themselves, and to handle the school apparatus. An examination of the work carried on in the Model National Schools in Ireland, will show that in many cases children of eleven and twelve years possess a fair knowledge of physics and chemistry, and when they do not possess this knowledge, it will be found that too much attention has been paid to Euclid and grammar, and perhaps practical geometry has not been studied at all.

Technical physics is the application of the principles of natural philosophy to particular trades. Thus, for instance, a man who makes steam-engines ought to be acquainted with the laws of heat, the behaviour of steam and water under different conditions, the properties of iron, brass, oil, &c., with stress and strain phenomena, and the strength of structures. His knowledge of the principles of natural philosophy ought to be such that he can imagine the molecular action going on when two surfaces rub together, when the volume of a gas or vapour is suddenly changed, when a piece of metal communicates forces. It is the resultant of all his knowledge, and notions, and instincts which he brings to bear upon a piece of metal that he is chipping or filing, and the greater is his knowledge, the more exact are his notions, and the truer to natural laws are his instincts, the better an engineer must he be. When a boy enters a workshop, however good may be his know-

ledge of the principles of natural science, he cannot readily understand all the operations going on about him. He must be taught the application of his knowledge to a particular trade. This application of his knowledge is really a higher study of physics. Technical physics is simply advanced physics, so advanced that the boy becomes a specialist. All his future life is that of an experimental physicist, who is attaining a greater and greater knowledge of a particular part of his subject. A workman enters more into direct converse with the laws of nature, and especially with what is called "molecular physics," than any other man. To him, too, nature speaks in a more complex way than to the laboratory student. The laboratory student may vary his temperatures, his pressures, his stresses at will, and may experiment on a phenomenon, making its conditions less and less complicated; whereas the workman has to take phenomena as they occur in his trade, using all the knowledge which different laboratory students may give him, so as to enable him to understand the complex phenomena really occurring before him.

Buckle brings out strongly the reasons why the aborigines of a country of great rivers, and earthquakes, and volcanoes, and tornadoes, are often so low in the scale of humanity. The actions of nature are so complex and mighty, that the human spirit is crushed. But when to such a country comes a race who have got to understand nature's laws, who can bridge the largest rivers, and build houses to withstand earthquakes and tornadoes, the opportunities given to such a race of fighting with and better understanding nature, may raise it to the highest civilisation. Our workmen have long been stolid enough, and have long enough given up ideas of understanding the complex phenomena with which they work, but give them a knowledge of physical science, such as we know will enable them to understand their work, and one year's advance in their knowledge of nature will be worth ten years of our present laboratory progress. English workmen are acknowledged to have greater manual dexterity than workmen of any other country, and I do not think that we can improve them in this respect. If you want a really perfect piece of work of any kind, where patience and honest painstaking labour are of chief importance, you must get it from an

English workshop. What, then, is the nature of the improvement which we want to see effected in English trade? The fact is, our workmen are machines, and we know that in time other machines will be constructed to do the same work at less than half the cost. There is none of that perfection of workmanship on which we vaunt ourselves which may not be done as well and cheaper by regular machinery. We see all this in time to make a reformation, and we hope to use the brains as well as the hands of our English workmen, as they are doing in the United States. Till now we have made little use of our workmen's brain power. It is a fact that every year in England we build structures and make machinery, using twice as much metal as is really required, following rule-of-thumb and precedent, and, in the fear of weakness, without having the power to calculate, we make things clumsy; we give perfection of workmanship where none is required; use the hands of thinking men in repeated operations of exactly the same kind, which much less costly machinery might be applied to; and neglect the use of valuable brain power so much that a new idea cannot be entertained, much less originated, and an English inventor must get a German or an American workman to carry out his notions. Highly as I think of the conservatism and the stolidity of Englishmen, I must confess that all this seems to me to cry out for a reform, whatever may be said in its favour by certain prominent men. England was first in employing her iron and coal, and, probably, she will always be in front of people despotically governed; but she acts like an extravagant rich man in making so little use of her great advantages. Any one who has been among Asiatics, and has seen how a common English sailor or English workman develops intellectual powers and ingenuity, and gets administrative ability, when circumstances place him in a position to develop them, must feel what a great waste there is in England, where all this brain power lies dormant, education and surroundings forbidding it to develop itself. We are all acquainted with good reasons for changing the apprenticeship system of England, and not long ago, in this room, a lecture was delivered, the gist of which was that the trade-school system of France and Germany should be planted in this country. I gave my reasons for dissenting from this view at the time,

and they have been more fully published in the *Electrician* of the 3rd inst. What is wanted in England is a good system of technical education, so that English workmen may be fitted to investigate the phenomena taking place before their eyes every day in the workshop.

It is possible that for a long time in any scheme of technical education, however good, we shall be opposed by difficulties which are due to educating only one man out of every twenty. An eminent manufacturer used to tell the story of how, when he was an apprentice, he discovered that a little schoolmistress got high wages from his master for translating his French correspondence. He thereupon began to learn French from this lady, and after some time his master discovered him by his books. The kindly reproof which he administered was worthy of our more modern opponents: "Eh, lad, tha mun stop that; tha'll never cut an English file if tha muddles th' yed wi' French." He paid for the books and teaching already given, and his apprentice never went on with his studies in this direction. A belief of this kind is too well fixed in the English mind not to be founded on good common sense. Partial education of a few workmen loses them the sympathy of their fellows, and gives them a weak sense of superiority to their work, which is apt to prevent their acquiring those instincts which are so necessary to good workmanship. This state of things will be reversed when the uneducated workmen are in a minority. I might use, as an illustration, the partial higher education of women, which tended, at the beginning, to make them lose their womanly qualities, but the general effect of which is already seen to raise them far higher in this respect than they ever were before.

For reasons given already, I believe that it is possible for children in the primary schools of England to acquire good notions of the principles of natural science, and hence that they will be in a position, on leaving school, to take up the study of technical physics as specialists. Some of these specialists will be called workmen, and some of them, whose parents are richer than others, or who have shown greater ability than others, will, after a course of laboratory work and more advanced study, become foremen and managers. Some will begin their trades at from twelve to fourteen years, and others at from seventeen to twenty years of age.

As the nature of the teaching of physics in primary schools, which seems to me best, has been sufficiently described already, I now propose to consider the more advanced kind of instruction which is to be recommended for boys between the ages of, say, from thirteen to fifteen and twenty years. Owing to the incomplete training which has, until the present time, been given to boys in schools, English professors have hitherto had to struggle with great difficulties in their college teaching, and, without being supposed to cast on them any reflections, I hope I may be allowed to express the opinion that advanced natural philosophy has not hitherto, in this country, been given a fair chance. Possibly, the teaching of chemistry in some colleges, and of physiology and anatomy in medical schools, quite come up to my ideas of what may be done in physics, but, for an example of a sufficiently good school of physics, we must look to the great laboratory established by Professor Ayrton in Japan. I exhibit photographs of the natural philosophy department and museum of the Yedo Technical College. I mention the museum, because the five or six rooms in this building, still unused for museum purposes, were taken up by students engaged in physical experiments.

It is easy to understand from the diagrams exhibited to the meeting, how the building specially intended for work in technical physics is portioned out. [Here the plans of buildings, the peculiar instrument cases, experiment tables, work-benches, &c., were explained to the meeting.] I cannot do better than read to you some extracts from an article in the *Japan Weekly Mail*, of October 26, 1878, on "A visit to Professor Ayrton's Laboratory":—

"Mr. Ayrton conducted us into his large lecture-hall: a narrow gallery, running round not far from the ceiling, and appendages to the ceiling, were, it was explained, for pendulum and other experiments requiring considerable vertical space. The lecture tables are reached by steps at the middle and on the ends of a platform, and these tables are supported on stone columns coming up from the foundations, and they are kept quite detached from the floor; the great peculiarity of the whole laboratory seeming to be that nearly every table in the place rests on columns of

masonry coming up from the foundations, and kept detached from the floors and walls, so that instruments resting on these tables may not be shaken by persons walking about in their neighbourhood. Every table in the lecture-hall is supported in this way, and as these tables are higher as they are farther away from the lecture table, it is easy to see that Mr. Ayrton had considerable difficulty in getting his views carried into effect. These firm tables form quite a new feature in lecture-halls, since it is now possible for students to actually illustrate the lectures by their own experimental work; and, besides, a great space is utilised which, when lectures are not being delivered, must usually be unoccupied. Besides these tables for students hearing the lecture, there are a great many tables round the walls of the room, not raised, and not supposed to be occupied by students attending to the lecture. These tables are of a new kind. It is possible for a student to leave his batteries and wires, his galvanometers, and little temporary contrivances, for, by pulling down a glass door, he shuts out dust and meddling hands. That there is a great saving of time effected by these shutters must be quite evident. We may just mention, that a great part of the apparatus required by the lecturer, or by the student, is arranged in glass cases round the room. . . . On looking over the collection of apparatus, much of which, however, was in use all over the place, we felt that neither the Cavendish laboratory nor the Oxford one, nor any others which it had been our privilege to see, could produce such experimental work as might come from this laboratory in Yedo, if only the men to use them were the same. We understood from Mr. Ayrton that it was possible for any student at any of the tables to turn on a tap of water or of gas (the gas arrangements had not then been completed), or a current of electricity, and that perhaps, in time, he might be able to coax the officials to allow him to convey separately hydrogen and oxygen to all the tables. We confess, however, that we felt more comfortable in knowing that Mr. Ayrton had not been able to carry this point of the explosive gases. Almost all the tables were occupied at the time of our visit, and we were informed that so eager were students to take advantage of the fine arrangements, that some of them, engaged in carrying out important investigations, had many times applied for per-

mission to work after ten o'clock at night. . . . Adjoining the lecture-room is a general laboratory, where the *kotskais* get ready apparatus ; but here, again, we saw the stone-supported tables, occupied each with its two or more students, who were, we believe, mainly telegraph students, testing lengths of wire and insulators and batteries, using Thomson's galvanometers, with their flashing spots of light, and peg-boxes, and batteries. The telegraph students were in this room where the vices and anvils, and tool-racks and furnaces were ; and some of them were making joints in telegraph wire, and they were all busy, and seemed to like their work, and they were evidently all well up to their work. This is a model work-room, the tool-racks all in that state of completeness which shows constant use and constant attention, the countless drawers each with its label, alphabetically arranged, the cases of apparatus overhead, and the general atmosphere of efficiency would have tempted the laziest of men into using files and hammers, and shellac. I applied one test before leaving the room, and that was not an electrical one ; I tried a few of the drawers, and I found that each really contained the copper or zinc, or twine, or sealing-wax, that it was labelled as containing, and there was a good supply. . . . I observed in one side passage that students were busy at heat experiments, and in another a great lot of batteries. Mr. Ayrton's private room comes next. Besides its writing-desk, and book-case, &c., it had the inevitable stone-supported tables, with vertical glass doors. Then came the large apparatus-room, glass cases all round, and a large set of cases in the middle of the room. Then a long, narrow laboratory which might be darkened, and out of it a small room, called for pre-eminence the dark chamber. In this sacred place were six columns of stone, each standing about four feet above the floor. Two were devoted to a Thomson's electrometer and its scale. This wonderful instrument had been taken to pieces some five times since its arrival in Japan, and it says much for the patience and skill of Mr. Ayrton and his students that the instrument was in good order. It is probable that this is the only specimen of the instrument which has survived even once being taken to pieces in a physical laboratory. I saw that one of the best students was gradually satisfying himself that even the best of these instruments gets intoxi-

cated once a day, and that the proper course of action of its caretaker is to let it alone for a while. Two other columns were devoted to a galvanometer. I understand that there are only two other galvanometers in existence which are as good as the one in question. . . . Of the remaining columns, one was devoted to an original investigation of the behaviour of twisted wires, and on the other was an apparatus to test a well-known Japanese belief regarding the effect of an earthquake on a magnet.

"Upstairs, a small class-room was used for lectures by such of the senior students as helped the professor in teaching. Next came a long room devoted to batteries. There were some three hundred Daniell's cells in working order, arranged in a glass case, and easy to get at, and many other cells in a clean state. Even to the construction of the troughs for soaking the porous cells and cleaning zincs, considerable thought had evidently been given, that there might be as little delay as possible in cleaning the cells. Mr. Ayrton told me that he had prepared some thousands of small Daniell's cells, each outer vessel being a piece of bamboo, but that the cheapness of the cell was its only recommendation, for a fungus growth of some kind interfered with the working. Beside this battery-room was the workshop, with lathes, carpenters' benches, &c. I found two workmen here, to one of whom a student was explaining something about a template. There were unfinished instruments and working drawings lying about. Beside this was the drawing office; some of the students were making working drawings of instruments, but the majority were reducing observations and drawing curves on squared paper.

"A large room, which seemed devoted to light experiments, with a great heliostat in the window, completed the rooms in the new buildings. But I proceeded to the old buildings of the compound, now devoted to museum purposes. It would take too long to describe fully the telegraph museum, with its specimens of all kinds of telegraphy, posts, insulators, sending and receiving instruments, &c. It is sufficient to say that every instrument was in working order, as one could tell by touching the various keys, when the clicking of the receiving instruments might be heard. Mr. Ayrton printed my name on a slip of paper, on the

other side of the room. In some of the smaller rooms of these old buildings we found students working at various investigations in heat, light, and electricity. We find it impossible to imagine that such work has been wasted. If we could share Mr. Ayrton's belief in the great power shown by some of his students, we might believe that a great school of scientific thought has been founded ; and although we venture to doubt the existence of sufficient capacity in the Japanese mind for high original scientific work when unhelped, still our visit to this, the finest physical laboratory which exists, perhaps, in the world, has impressed us with the notion that those students whom we saw working will yet leave an important impression of their own upon the history of science."

The account from which I have been quoting gives the impression that the experimental work was mainly in electricity, but this was probably due to the visitor having come on a day when there were more telegraph students than others, or, perhaps, the visitor was a telegraph engineer, for experiments were constantly going on in all parts of natural philosophy.

It will be observed from this description that the great objects which Professor Ayrton had in view, and which, I am in a position to say, were carried out with great success, were that :—1. His elementary lectures could be illustrated to some extent by the students themselves. 2. His students stayed with him a long enough time, and in sufficient numbers, to make laboratory work an important part of the scheme of instruction. 3. He could, to advanced students, make his lectures technical, that is, he could assume a knowledge of the principles of natural science, and show how these principles were employed, not merely alone, but in conjunction with each other in telegraphic engineering, and in other departments of applied physics. 4. His students, without disconnecting themselves from the natural philosophy department, could attend lectures on such parts of technical physics as did not come within the province of Mr. Ayrton himself, mechanical engineering, and applied mechanics of all kinds, &c. 5. Even when students conducted experiments in the engineering laboratory, they were taught to consider themselves as still continuing their

researches in natural philosophy. In consequence of all this, probably every one of the great number of workers in the establishment was full of an idea of the importance of the work he was doing, and was constantly becoming more intimately acquainted with the laws of nature. Because of the investigations which were put in the care of advanced students being of an original kind of some value to the general world, each such student was really cultivating habits of observation, and a reasoning power which would not easily be destroyed, however much of a routine there might be in his future profession. It would be too much to say that any of our students ever developed a power of originating experiments, because this power can hardly be expected until after the age of twenty, but many of them did pursue work of their own towards this end. Thus I remember discovering a boy striking, one by one, about a thousand matches, half in and half out of a beam of light, to discover the effect of sunlight on a fire; and I have no doubt that Professor Ayrton could give many such instances of developed originality. Our system of getting original work performed was open to the objection that when an experiment had been designed, and students were left to themselves to carry it out, it would often proceed for some weeks without any of the alterations of apparatus which would have suggested themselves to the professor if he had conducted the experiment himself. This never occurred with the more advanced students, however. A striking example of such a difficulty is now in my hands. From a notion of getting minimum distortion at all points in a map, a method of drawing it was arrived at, and two students were asked to carry out the idea. It was only after a month's quiet work that the elaborate descriptive geometry method of projection, which these students employed, was found to give the same results, and to be, in fact, identical with well-known stereographic projection. It is needless to say that the discovery would have been earlier made by the professor, if he had been engaged on the work himself.

Now, all this sort of teaching seems to me perfect as the beginning instruction in technical physics. To begin, so to speak, in the middle of the subject, to make students acquainted with natural philosophy through their own experience of instruments and machines, and of substances

subjected to various operations. For we found that such students worked up all the early parts of natural philosophy with some earnestness after they got to have a knowledge of the matters to which more elementary studies gave an explanation. It will at once strike everybody that such students as these had very little difficulty in understanding lectures upon manufacturing operations and machines, and that on entering actual workshops they became expert workmen in much less than the usual time.

I hope that nobody will say that in all this I have been merely describing the teaching of pure physics, and that technical physics is quite a different matter. The fact is, it is impossible to say at what period such students as those of Mr. Ayrton began their technical education. Taking, for instance, telegraph engineers. I am quite sure that these students saw no sudden break in the nature of their teaching; it was all technical from the day when they first, with a small but pretty exact knowledge of elementary physics and mathematics, and practical geometry and drawing, took up work in the laboratory. I am sure, also, that no mechanical engineer saw any break in his course until he left the college for workshops. He went about from Mr. Ayrton's lecture-room and laboratory, to the drawing-office and lecture-room and workshop-laboratory of the professor of applied mechanics, and to the lecture-room of the experienced instructor who taught him the theory of certain mechanical operations, such as welding, chipping, filing, turning, riveting, and the like; but all the time he knew he was learning how to apply the principles of natural philosophy to the affairs of his future profession. But he is learning much more than this, for all his laboratory experience has taught him that the explanations he hears of the behaviour of materials under strain, of molecular actions when metal is cut, are incomplete, and he has learnt that he is in a specially good position for making it more complete. He has learnt that no machine or instrument in use is perfect, but may be made better if he bestows thought upon every detail of its construction. He has learnt to imagine what is actually being done in each operation which he may be put in charge of in the workshop, and knows that it is in his power to get that operation performed in a better way. He has learnt, too, that great patience and quiet thought

are necessary if he wants to study well any phenomenon that comes before him. I consider that such students as these have got all the benefit which it is possible to get at a technical college. Their further study is that of specialists. They must teach their hands and eyes in the manufactory, and read what is written by other men who have been in the same position as themselves, but their education can only finish when they cease to work.

Let us now consider how common workmen shall learn to apply the principles of physics to their trades. Either through their early training, or from science and art classes, we are to suppose that workmen of the future will have a knowledge of practical geometry and mechanical drawing, they will know elementary natural science, and, perhaps, a little algebra and trigonometry. If they are suddenly thrown into a factory, to make materials obey their wishes, and see how other men do their work, I consider that to teach them the applications of their previous knowledge will be easy enough, if only we can provide for them teachers and schoolrooms near their factories. For it is to be observed that, of technical class-books for such students we have plenty already, and of illustrations of the instruction they get their factories are filled. We may be quite sure that schoolrooms will not be wanting when the teachers are ready, and the only teachers worth having are men who have been trained in an establishment like that just described, and who have also passed through the factory.

Passing from this great question of the future to the present necessity—what is to be done for workmen just now—men, one out of every twenty of whom has attended science and art classes, but who may be looked upon as knowing little or nothing of the elementary principles of physics? They are experimenting among the most complicated phenomena, and we must teach them to understand what they do and see. Now, the standing rule in teaching is that we ought to use, as illustrations, those things with which pupils have most to do. Here then we have to follow the idea already sketched out; we must begin somewhere in the middle of our subject, working both backwards and forwards; and, as I said before, it really does not much matter where we begin. This kind of instruction is still in its experimental stage, or rather experiments have just been

begun in it. If, as a result of experiment, we were able to tell what is the best way of teaching apprentices and workmen, if we could write out a regular programme for each trade, and could say that it is good, I am quite sure that the establishment of schools all over the country would be the work of a few years only. It is all very well for us to blame English manufacturers for not educating their apprentices, but we do not see the magnitude of the work which we propose to them. How often have learned professors given short courses of lectures to working men ; how many classes have been established in mechanics' institutes and elsewhere ; how much work of this kind has been tried we all know, and with what want of fruition. All the experiments have given more or less unsatisfactory results. One reason for this is, that possibly no able physicist has cared to study patiently the question year after year, varying his method of teaching to find the best ; another is that the matter has never yet been taken up on a large enough scale, so that, for instance, one class might be formed of students who are in anything like the same condition for pursuing their studies ; and lastly, there has been no way of compelling or inducing everybody to continue his studies for two or three years. For the great central difficulty in such an experiment is that the services of the teacher, and the attendance of the students, have always been voluntary. A little want of patience on either side, and the experiment ceases. That a competent man be induced to continue his experiment for several years, provided he is assured of his pupils coming to him in a certain state of preparation, and also of their attending with fair regularity for several years, these I look upon as conditions of more importance than any others if the experiment is to prove successful, in telling to us what is the best scheme of education in technical physics for workmen. I lay some stress on these necessary conditions just now, because I have studied carefully the method of teaching which Mr. Ayrton is employing for the City and Guilds of London Institute, in his lectures on "Applied Physics," at Cowper Street, and I think that this method promises more success than any other which I have heard of ; and I fear that it will fail, on account of the above conditions not being carried out. His method is succinctly stated at the end of his syllabus :—

"The aim of these lectures on technical physics will be to train the students, by an examination of the machines, instruments, &c., employed in the arts (or of models of them), to turn their attention to the scientific principles governing the action of these machines, without a knowledge of which neither their proper working can be ensured nor improvements in them effected. It is believed that the analytical method of experimental instruction, in applied physics, will, for the class of students expected to attend, be preferable to the ordinary method adopted in the teaching of natural philosophy, which consists in much time being spent in the study of the elementary principles, and then only subsequently the practical applications explained."

Perhaps his meaning will be better understood if I read a paragraph from his syllabus—

"*Variable Rate of Going.*—All watches gain or lose; chronometers gain or lose uniformly, ordinary watches have a variable rate; acceleration; Newton's second law of motion, methods of proof; retardation, brakes, compressed-air brakes, vacuum brakes; effects of heat on the springs of a watch, on the pendulum of a clock; compensations; the vibrations of balance-wheels and of pendulums are examples of simple harmonic motion; is the result of a force acting proportional to the distance; spring weighing machines; the vibrations of bodies emitting musical notes; tuning-fork governors for clocks," &c.

It is to be understood that he is taking up, more particularly, in these lectures, the principles of watch and clock-making, and it will be seen that he reasons from that part of the subject which his students know, namely, from the appearance and uses, and construction of the various time-keepers shown to them, backwards (or forwards), to those mechanical and physical principles with which most men begin to study a technical subject. In doing this, he makes use of all the knowledge and habits of thought which he supposes workmen to have, illustrating his lectures by means of experiments. Mr. Ayrton then goes on the principle that we may begin to teach physics at any point we please, so long as our students are thoroughly convinced (or can

become convinced by examination and observation) of the truth of the data with which we begin. He here begins by showing clocks and watches such as everybody has seen. Everybody knows that they are time-keepers, and that they need to be wound up, and that they gain or lose on each other slowly, and he works on this basis until he has traced out clearly all the physical principles involved in his subject.

I say that this is the most promising method I know of, but it will undoubtedly fail to give satisfaction unless the scheme of technical instruction at Cowper Street is large enough for the proper carrying out of any such experiment. It has been proved, over and over again, that trifling fugitive experiments of this kind are of no use whatever, and, indeed, the more promise they show at their inauguration, the more harm they do when they prove unsuccessful, for it is to be remembered that the result of the failure of an experiment is the disheartening of students, clinching the opinions of the many opponents of technical education, and losing the sympathy of manufacturers throughout the kingdom. We have already had more than enough of these unsuccessful experiments, begun with enthusiasm, and ending rocket-like in burnt-out sticks.

PREFACE TO AN ELEMENTARY BOOK ON PRACTICAL MECHANICS PUBLISHED IN 1881

THIS is an attempt to put before non-mathematical readers a *method* of studying mechanics. The student will not benefit much by merely reading the book, nor will he benefit much even if he supplements his reading by listening to lectures on mechanics; but I believe that if by means of lectures he obtains a thorough comprehension of the book, and then makes common-sense experiments with the simple apparatus which is to be found even in the poorest laboratories, but which has hitherto been used merely to illustrate lectures; if, in fact, he uses this book to study mechanics in the manner herein recommended, he will gain in a short time such a working knowledge of the subject as will well repay his labour. I am quite sure also that the mental training acquired in this way is of a kind not inferior to that the belief in which retains in our schools the study of ancient classics and Euclid.

The principle of my method is one which I have tested in practice during the last twelve years, in an English Public School, at the Imperial College of Engineering in Japan, and in other places. It is simply the practical recognition of the fact that all experimenting must be quantitative. It may exercise the wonder of a child, it may please his senses to see certain well-known lecture illustrations which are but little better than tricks, and possibly for young children there may be great instruction in such exhibitions, but they contain no instruction for thinking men who can obtain sufficient amusement elsewhere. Our subject must be studied through quantitative experiments, and when this method of study is adopted it is but of little consequence at what part of the subject the student begins,

so long as he begins from his own natural standpoint, the standpoint given him by all his experience.

The primary fact in technical education not yet sufficiently recognised is this—that illiterate men often acquire and possess a useful knowledge of the principles underlying their trade. But the theory usually acted upon is that a man must be quite ignorant of the principles of his trade unless he has been led up to them through weary years' study of the elementary principles of science. On the contrary, the wise apprentice sees for himself that some illiterate journeyman gets good wages, is well thought of by his master, is able to do his work better, perhaps, than any other man in the shop, can be trusted in emergencies, and has a confidence in himself which experience justifies; and the apprentice feels that although the journeyman might be a better workman if he knew the elementary principles of science, still, somehow or other, he has gained an exact knowledge of those more complicated laws with which he has to deal in his trade.

It is good for a man to know the well-established elementary principles of science, to which all complicated laws can be reduced; this enables him to compare his own experience with that of all other people, and enables him to make better use of his own observations in the future.

In giving this knowledge, however, the usual plan of operations is to act on the assumption that the man knows nothing, because he did not begin his previous study with Euclid's axioms, and to teach him the elementary principles as schoolboys of no experience are taught. Now, the standpoint of an experienced workman in the nineteenth century is very different from that of an Alexandrian philosopher or of an English schoolboy, and many men who energetically begin the study of Euclid give it up after a year or two in disgust, because at the end they have only arrived at results which they knew experimentally long ago.

I am inclined to believe that if, instead of forcing the workman to study like a schoolboy, we were to teach the boy as if he had already acquired some of the experience of a workman, and made it our business to give him this experience, we should do better than at present. That is, let the boy work in wood and metal, let him gain experience

in the use of machines, let him use drawing instruments and scales, and you put him in a condition to understand and appreciate the truth of the fundamental laws of nature, such a condition as boys usually arrive at only after years of study. It is true he may regard the 47th proposition of the First Book of Euclid as axiomatic; he may think the important propositions in the Sixth Book as easy to believe in as those of the First; he may have greater doubts as to the universal truth of these propositions than mathematicians usually have; but it is possible that these evils are not unmixed with good.

The readers of this book are supposed to have some previous knowledge of the behaviour of materials and machinery. My aim is to give the student such a training as will cause him to think exactly, to give him a method of studying whatever phenomena happen to come before his eyes. Phenomena which, when carelessly considered in the light of elementary principles, appear to follow complicated laws are often found to follow approximately simple laws of their own. A man who knows these roughly correct laws is in a good position for learning the fundamental principles of mechanics; but his teacher must try to view the subject from his student's standpoint, else he cannot take advantage of the fact that his pupil may already possess an excellent foundation on which a superstructure of knowledge may be built. I believe that the most illiterate of men may be rapidly taught practical mechanics if we take the right way to teach them—approach the subject from their point of view rather than compel them to approach it from ours.

In a book which is to be used as a general class-book by boys and men it is impossible to assume that the reader has an extensive previous practical acquaintance with natural phenomena; but it will be seen that some such past experience is assumed, much more than is usually ascribed to the ordinary student of mechanics. Moreover, he is credited with the possession of common sense, and with the feeling that all human knowledge, instinctive and rational, is the result of experience.

There is much in this book which may seem new to the reader, but inasmuch as I have been, and still am, a student, and as no man can go through life without gathering to

himself and regarding as his own many notions of other men, it is probable that there is nothing here, either in the matter or method, which is wholly my own. My partnership in scientific work with Professor Ayrton during the last seven years would in itself preclude any thought of such ownership. For the treatment of some parts of the subject I know that I am indebted to my recollection of the lectures of Professor James Thomson, delivered when I was one of his students fourteen years ago. How much is owing to Sir William Thomson, to Thomson and Tait, and to Professor Ball it is quite impossible to say.

For the careful correction of proofs I have to thank my assistant, Mr. William Robinson, M.E., who has taken as much pains to eliminate numerical errors, puzzling sentences, and crudities of language as if the book had been his own.

JOHN PERRY.

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